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NOTES ON INTERNATIONAL SCIENTIFIC MEETINGS

REVIEW SECTION

IGR TRANSLITERATION OF RUSSIAN[1]

The AGI Translation Center has adopted the essential features of Cyrillic Transliteration recommended by the U. S. Department of the Interior, Board of Geographical Names, Washington, D. C.

Alphabet		transliteration
А	а	a
Б	б	b
В	в	v
Г	г	g
Д	д	d
Е	е	e, ye (1)
Ё	ё	ë, yë
Ж	ж	zh
З	з	z
И	и	i (2)
Й	й	y
К	к	k
Л	л	l
М	м	m
Н	н	n
О	о	o
П	п	p
Р	р	r
С	с	s
Т	т	t
У	у	u
Ф	ф	f
Х	х	kh
Ц	ц	ts
Ч	ч	ch
Ш	ш	sh
Щ	щ	shch
Ъ	ъ	" (3)
Ы	ы	y
Ь	ь	' (3)
Э	э	e
Ю	ю	yu
Я	я	ya

However, the AGI Translation Center recommends the following modifications:

1. Ye initially, after vowels, and after ъ, ь. Customary usage calls for "ie" in many names, e.g., SOVIET KIEV, DNIEPER, etc.; or "ye", e.g., BYELORUSSIA, where "e" follows consonants. "e" with dieresis in Russian should be given as "yo".

2. Omitted if preceding a y, e.g., Arkhangelsky (not iy; not ii).

3. Generally omitted.

NOTE: The well-known place and personnel names that have wide acceptance in international literature will be here adopted. However, German-type transliteration e.g., J for Y will not be used.

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[1] Due to the individual training and tastes of the translators and reviewers whose work is published in this issue of IGR., it has been impossible to follow the above recommended system. In the near future, however, an effort will be made to standardize transliteration procedures.

A CONTRIBUTION TO THE GEOCHEMISTRY OF RESERVOIR FORMATIONS: THE LOWER FRASNIAN OF THE VOLGA-URALS[1]

(Part 1 of 3)

by

N. M. Strakhov, K. F. Rodionova, and E. S. Zalmanzon

• translated by Mark Burgunker •

ABSTRACT

The hydrocarbon concentrations in rocks of Frasnian, Givetian, and Famennian age are considerably higher than the concentrations in other units in the Devonian section of the Volga-Ural province, U. S. S. R. The maximum hydrocarbon concentration occurs in the Domanik, which is the host for the largest accumulation of ancient organic material on the Russian platform.

The correlation of hydrocarbon A with oils and other hydrocarbons and with organic carbon is very low. Trace elements are distributed uniformly throughout clastic sediments and differentially in precipitates, including clays, marls, and limestones. Iron, manganese, phosphorus, copper, and strontium concentrations increase as the host rocks become more clastic; chromium, niobium, and cobalt decrease. This difference is an additional criterion for mapping ancient pelagic zones and shoreline. However, weathering may lead to artificial concentrations for the various elements.

INTRODUCTION

Before now, petroliferous rocks had been generally considered in relation to their paleogeographic environment and as hydrocarbon reservoirs. The scale of geochemical investigation of producing horizons, especially the study of disseminated (primary) hydrocarbons in these horizons, has been small. The problem of petrographic control has been little considered. Petrographic analysis of petroliferous rocks is a major aspect of the general geochemistry of sedimentary rocks. It is also of some practical significance inasmuch as its solution may shed some light on the still unsolved question of the origin of petroleum.

An examination of the published literature (papers of Radchenko [30-32], Uspensky [42-46], Putsillo [29], Guyayeva [12-13], and others) indicates the widespread random and unsystematic selection of rocks and hydrocarbons to be investigated, lack of stratigraphic correlation and sample identification, and absence of reference of chemical investigations to sample lithofacies, thus rendering any lithogenetic interpretation of the data doubtful. The scope of investigation is generally limited and the program simply does not include integration of data within a larger context. This is why methodology of comparative geochemical studies has not been developed, especially for hydrocarbon studies.

This paper is an attempt to present a comprehensive comparative geochemical investigation of lower Frasnian [Upper Devonian] petroliferous sediments of the Volga-Urals province. It involves a very detailed examination of bio- and lithofacies context of specimens and data. The authors have tried, as far as possible, to go beyond the narrow framework to which empirical and published data would confine them, and to develop a broader framework for certain aspects of the problem.

It is well known that the Pashysky zone of the lower Frasnian is a reservoir zone. Siltstones with which the reservoir rocks alternate contain disseminated primary hydrocarbons. During exploratory drilling, much organic matter and many petroleum droplets were discovered in the Domanik beds. But what are the disseminated hydrocarbons in the Pashysky and Domanik beds? what is their geochemical nature? and what is their relationship with the commercial pools in the Pashysky zone?

The lower Frasnian of the Volga-Urals contains a large amount of organic matter and many small iron deposits. Does the presence of iron, manganese, and phosphorus affect the occurrence of disseminated iron, manganese, and phosphorus minerals? In other words, is the occurrence of (localized) iron deposits in direct function of a regional concentration of iron minerals? Certain trace elements, vanadium, chromium, nickel, cobalt, and copper, are also present. Measuring the concentration of these elements in the various types of sedimentary rocks and correlating their concentrations and relative amounts of organic matter, carbonates, and iron may yield additional information concerning the geochemistry and origin of petroliferous sediments.

Fifty-four cores taken during the 1949 field season, along the Teplovka-Syzran-Sernovdsk-Yerykly-Tukmakly-Tuymazy-Kargaly line (fig. 1)

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[1] Translated from K geokhimii neftenosnykh otlozheny (inzhnefranskiye porody Vtorogo Baku): Akademiya Nauk SSSR, Trudy, Instituta Geologicheskikh Nauk, Geologicheskaya Seriya, no. 66, vol. 155, p.3-115, 1955. Parts 2 and 3 of this work, including the references list, will be published in succeeding issues of International Geology Review.

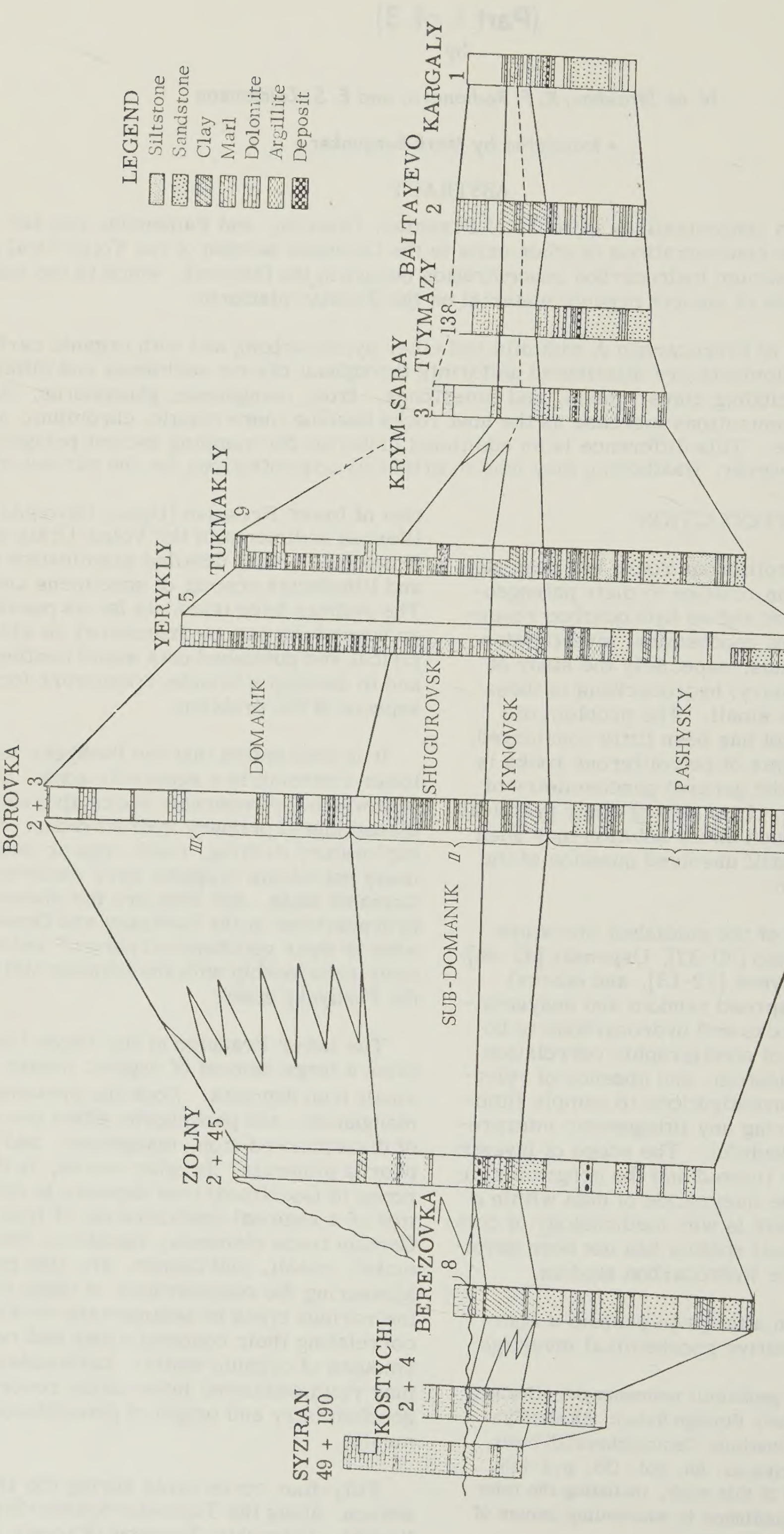

FIGURE 1. Correlation of drill-hole cores along the Teplovka-Kargaly line

yielded approximately 8,000 samples. [Teplovka, 51°30' N. 51° 31'E.; Kargaly, 55° 16'N. 54° 48' E.] Only 22 cores were complete; therefore, the inferred cross section is incomplete.

Samples were petrographically and stratigraphically studied in order to increase the accuracy of the interpretation of conditions under which lower Frasnian sediments were deposited and to establish the total organic-matter, calcium carbonate, magnesium, iron, manganese, and phosphorus contents. The quantity of organic matter was determined by burning samples in the presence of chromium anhydride and H_2SO_4 (the amount of free carbon was assumed to be equal to the amount of organic matter). Special experiments demonstrated that the most accurate values were obtained when high concentrations of sulfuric acid were used.

Hydrocarbon components of 25 samples from Pashysky, sub-Domanik, and post-Domanik beds were compared with petroleum, coal, sapropel, and asphalt of lower Devonian commercial pools. Ninety-one samples were tested for trace elements. M. A. Rateyev studied the mineralogy of clays in the reservoir beds and the sub-Domanik, for colloidal clays serve as catalysts for the transformation of hydrocarbons.

This paper is a summary of all our investigations. More detailed reports on various aspects of the study have been published by E. S. Zalmanzon and E. S. Shishova [18], E. S. Zalmanzon and N. V. Lizunov [17], and M. A. Rateyev. Rateyev and S. L. Afanasiyev participated in the investigation and correlation of the cores with N. M. Strakhov. Carbon, carbon dioxide, iron, manganese, and phosphorus analyses were made by R. M. Mikhaylov and A. N. Zerubitzkaya at the chemical laboratory of the Cooperative Lithology Department of the Academy of Sciences, U. S. S. R. Total organic matter was measured by K. F. Rodionova, with the assistance of E. I. Roslova and K. B. Sokolova, laboratory technicians. Trace-elements analyses were made by E. S. Zalmanzon and F. S. Shishova [18].

STRATIGRAPHY OF THE LOWER FRASNIAN ALONG THE TEPLOVKA-SYZRAN-TUYMAZY-KARGALY LINE (by N. M. Strakhov)

The Lower Frasnian Sequence in the Vicinity of Sernovodsk No. 3, Borovka No. 2, and Borovka No. 3

The lower Frasnian in this area is approximately 480 meters (m) thick and consists of three essentially different stratigraphic components:

1. The Pashysky is approximately 170 m thick. It consists of alternating white sandstone and gray (occasionally greenish or reddish) irregularly bedded siltstones. Greenish or red clays appear at certain levels, as do occasional thin beds of dark-gray marls and limestones. Organic remains, unidentified brachiopods and brachiopod fragments, as well as brachiopod waste, are rare, although considerable concentrations are sometimes encountered. These fossils do not provide a basis for dating. Spores and pollen, identified and described by S. N. Naumov, are Upper Devonian. The rocks from which these flora were taken therefore belong to the lowermost Frasnian.

The lower limit of the Frasnian is not clearly defined in this area. It is therefore arbitrarily set. A sequence, lithologically similar to the Givetian, lies below this limit. This lower component is correlated with the Pashysky on the western flank of the Urals on the basis of lithology and stratigraphy.

2. Overlying the Pashysky sandstones and siltstones conformably are 120 m of sub-Domanik clays and marls. The contact between Pashysky and sub-Domanik beds is marked by 1 to 1.5 m of limestone which registers sharply on electric logs. The basal layer of the sub-Domanik consists of comparatively thin siltstones. These are overlain by dark-gray and greenish, slightly carbonaceous clays which alternate with smaller lenses of siltstone and thin beds of dolomite. The clays contain pelecypods, *Estheria*, small brachiopods, and fragments of larger brachiopods. The siltstones are approximately 40 m thick.

Overlying the argillaceous component of the sub-Domanik are gray marls with many subordinate layers of gray limestone and dark-gray, or nearly black, and occasionally chocolate, limestone. The clays and marls are abundantly fossiliferous. Their distinctive faunal assemblage includes pteropods *Styliola* and *Tentaculites*; brachiopods *Lingula* and more rarely *Ladogya*, representatives of the genus *Pterachoenia* (*Pt. cf. lupina*, *Pt. fragilis*, *Pt. coshaque*), *Buchiola*, *Ontario*, and others; as well as the cephalopod *Bactrites*. On the whole, this assemblage is characteristic of the overlying Domanik. The sub-Domanik, except for certain layers, is generally poor in fossil remains. It does not have the characteristic odor of petroleum which is always associated with the Domanik. An abundance of pyrite nodules also characterizes the sub-Domanik.

3. Most of the 190-m-thick Domanik sequence consists of pure and argillaceous limestones; clays are present in the lower portion. All rocks are dark gray or black, rich in organic material, and give off a strong petroleum odor. The faunal assemblage contains *Tentaculites*, *Styliola*, *Pterachoenia*, *Lingula*, *Buchiola*, and others; unfortunately, incomplete cores allowed

only a general picture of the cross section.

The Lower Frasnian West and East of the Sernovodsk-Borovka Area

The Pashysky, sub-Domanik and Domanik are present over the 700-kilometer cross section along the Teplovka-Syzran-Tuymazy-Kargaly line. The lithology of these stratigraphic subdivisions vary laterally, however. The Pashysky sequence, east of the Sernovodsk-Borovka area, can be traced as far east as Kargaly. Its thickness decreases from 125 to 130 m at Tukmakly to 75 m at Krym-Saray, and to 55 or 60 m at Tuymazy. Its lithology is dominantly sandstone and siltstone, but east of Krym-Saray, the carbonate content increases. A limestone bed is encountered in wells over the entire length of the cross section.

At some points (Tuymazy, for example), the Pashysky is divided into an upper and lower unit by a clay bed. The upper unit is referred to as the Narysh zone; the lower as the Ardatovka zone. These two horizons can be distinguished with a fair degree of certainty at Baltayevo and Kargaly, and less clearly at Krym-Saray. The two are indistinguishable in the west at Tukmakly and Yerykly. It can be definitely identified in the Sernovodsk-Borovka area. It is possible that the degree to which the division can be identified depends upon the quality and length of the core taken from a given well.

The Pashysky sequence can be traced to Samarsk Bend and Syzran west of Sernovodsk. Its thickness decreases to the west and, in some areas (particularly at Kostychi), it seems to disappear entirely. The absence of fossils in this area makes a purely lithologic correlation questionable. The differentiation of the Ardatovka and Narysh zones is extremely difficult in the Samarsk Bend area and impossible at Kostychi and Syzran, where the lower Pashysky is pinched out and sharply reduced in thickness.

A terrestrial Pashysky facies is encountered southwest of Syzran and Saratov, according to Kondratyeva and Yengurazov [15]. These investigators write, "The sequence consists of green-gray, gray, and white sandstones and siltstones with gray, green-gray, and dark-brown clays and shales. Occasional layers of argillaceous limestones and marls occur in the upper part of the sequence; a few specimens of Cyrtospirifer ex gr. murchisonianus Kon., as well as stegocephalian remains, are found in these sediments." The thickness of the sequence is between 209 and 232 m, but decreases to about 160 to 170 m at Sokolovy mountain. It should be noted, however, that the Pashysky in areas east of Samarsk Bend does not contain Cyrtospirifer murchisonianus Kon. Therefore, the upper Pashysky of of the Saratov section may actually be a lower sub-Domanik facies.

The lithology of the sub-Domanik varies considerably along the Teplovka-Syzran-Tuymazy-Kargaly line. Its thickness decreases rather sharply east of the Sernovodsk-Borovka section; it is only 25 or 30 m thick in the Krym-Saray-Kargaly area. A fundamental lithologic change seems to be associated with the decrease in thickness: the carbonates comprising the entire portion of the sequence in the former section are replaced by green-gray and red-gray shale. Beds containing abundant organic material also disappear in the eastern sections; these beds are encountered more frequently in the sub-Domanik than in the Pashysky. The fossil assemblage includes Cyrtospirifer murchisonianus Kon., pelecypod remains, and other forms. The geologists of Bashkiria have assigned the name Mikhaylovsk to this argillaceous facies.

Approximately 100 m of Pterachoenia coshaque-bearing shales in the Zolny Ovrag section of Samarsk Bend may belong to the sub-Domanik. The thickness of this sequence of siltstone, shale, and limestone, which can be correlated with the sub-Domanik, suddenly decreases to 40 m at Berezovka, where green shales containing Lingula, Estheria, and goniatite (!) remains pass upward into gray-green marls. A layer of oölitic limonite occurs at the base of the marls.

The basal siltstones, which are partially calcareous, contain Cyrtospirifer ex gr. verneuili, Schizophoria ex gr. striatula, Atrypa, Velykaya, Conularia, and Lingula. Occasionally, these sediments contain only plant remains. The upper portion of the sub-Domanik consists of gray-green shales with subordinate limestone beds. The latter contain Cyrtospirifer murchisonianus, Schizophoria striatula, Atrypa, Lingula, and Tentaculites. C. murchisonianus dates these beds as definitely sub-Domanik, but limestones containing Voronezhsh [Tr.: upper Frasnian] fossils generally overlie sub-Domanik sediments. This indicates a hiatus between the sub-Domanik and Voronezhsh sediments in the Syzran-Kostychi-Berezovka section, which probably occurred during Semiluksk time [Tr.:Domanik]. It is possible that the Semiluksk sediments were eroded and redeposited as sub-Domanik [Ed.: post-Domanik ?] sediments.

Sediments corresponding to the sub-Domanik in the Saratov area have a maximum thickness of 107 m in Kazanlinsk Well No. 7. But the sediments which are mapped as Pashysky are probably sub-Domanik; consequently, the actual thickness is probably considerably more than 100 m. The clays which Kondratyeva mapped as Pashysky in the Saratov area are very similar to those called sub-Domanik in the Sernovodsk-Borovka area. In both cases, the argillaceous sediments which comprise the lower sub-Domanik are overlain by calcareous marls with diagnostic Tentaculites.

Kondratyeva and Yengurazov write that "the Shchigry sequence (Strakhov: treated as sub-Domanik here) consists of argillaceous-calcareous deposits; more specifically, these are gray or dark-gray limestones which are microcrystalline, pelitic, and frequently argillaceous. The diagnostic faunal assemblage includes Hypothyridina calva Mark., Schizophoria tullensis Venuk., and Lamellispirifer novosibiricus Toll. Faunal distribution is highly irregular vertically; some layers are literally saturated with fossils, others are nearly barren." [22].

The Domanik sequence shows more horizontal lithologic uniformity than does the sub-Domanik. The thickness of the sequence decreases from 140 m in the Sornovodsk-Borovka section to between 25 and 40 m in the Krym-Saray-Kargaly section; the lithology, however, remains unchanged. The typical Domanik sequence in the Zolny Ovrag section of the Samarsk Bend region is 80 or 90 m thick. It consists of reddish and greenish clays. Pterachoenia is diagnostic for the sequence.

The Domanik corresponds to a hiatus in deposition and to subsequent erosion. This may be the reason why the Domanik at Zolny Ovrag is entirely argillaceous. The Semiluksk sequence, in the Saratov area, is the counterpart of the Domanik. Kondratyeva and Yengurazov write, "the Semiluksk consists of argillaceous-calcareous rocks. Its base is an almost black, thinly laminated, bitumenous limestone which gives off an odor of burning rubber when it is exposed to flame. These limestones are overlain by laminated argillaceous limestone with subordinate conglomerates which included lenses of argillaceous marl. An abundant brachiopod tentaculite, and algal (Strakhov: ?) fossil assemblage occurs sporadically. The limestone varies in color from almost black to gray.... The sequence is dated on the basis of an assemblage which consists of Cyrtospirifer disjunctus Murch., Liorhynchus pavlovi Muffke, and Lingula subparallela Sandb." [15].

Thus, the lower Frasnian consists of three conformable and lithologically dissimilar sequences which retain their stratigraphic identities over a 700-kilometer cross section; the thickness and lithologic character of the three vary, however. The total thickness of the lower Frasnian is least in the Samarsk uplift and major components are missing from the section. This thinning is due to the pinching out of the Pashysky (in the lower portion) and to a hiatus which corresponds to the Domanik (in the upper portion). The lower Frasnian is thickest southwest and east of the Samarsk uplift. All three sequences are represented in these areas. The sub-Domanik is divided into a lower argillaceous unit and an upper marl-limestone unit. The latter contains a typically Domanik fauna and even clay beds in which the content of organic matter is high. The total thickness again decreases in the extreme eastern portions of the cross section, but the stratigraphy remains unchanged, and the sub-Domanik is not differentiated.

Units of lower Frasnian age can be correlated as follows: 1) the Pashysky and sub-Domanik together correspond to the Shchigry, as determined by Pistrak [27] and others: 2) the Domanik, in general, corresponds to the Semiluksk; and 3) the sediments mapped as Pashysky in the Saratov area represent a substantially longer interval of time than that which is represented by Semiluksk sediments.

Quantitative Relations among Lower Frasnian Lithofacies in the Syzran-Kargaly Section

Percentage distributions of sandstones; siltstones; and clays, marls, and limestones were computed for Pashysky samples for which cores were taken. It was assumed that nonassayed Pashysky samples in areas where cores were not taken were identical with the assayed samples. This assumption permitted a general overall distribution pattern. In some cases, well-logging data supplemented assay values. The quantitative relationships of sub-Domanik lithofacies were treated in the same manner. As the Domanik did not contain sandstone and siltstone, only the clay-marl-limestone components could be measured (table 1).

The values, although approximate, indicate the subordinate position of the clay-marl and limestone facies in the Pashysky sequence. The greater part of the thickness, between 73 and 80 percent, is divided evenly between sandstones and siltstones. Locally, either sandstone or siltstone may predominate. Rock in which coarse-grained sediments predominate and in which clays, marls, and limestones are subordinate, can serve as reservoirs. Subordinate fine-grained beds are particularly favorable for entrapment. It should be noted that the eastern portion of the cross section, from Krym-Saray to Kargaly, contains somewhat more clay-marl than does the western section.

The sandstone and siltstone facies are very minor components in the sub-Domanik; they are best developed near the Samarsk uplift. They are absent in the Domanik. In addition, Domanik sediments are separated from the (potential and actual) reservoir sandstones and siltstones of the Pashysky by a considerable thickness (from 27 to 110 m) of weakly permeable marls and clays. The overlying post-Domanik, Voronezhsk, and other beds consist of dense limestones (partly dolomitic) which are impermeable to water and oil. The clay and marl facies of the Pashysky and Domanik are surrounded by permeable and impermeable rocks, respectively.

TABLE 1. Proportions of sedimentary rocks in the lower Frasnian.

Rocks	Kostychi Nos. 2 and 4	Berezovka No. 8	Borovka Nos. 2 and 3	Tukmakly No. 9
Pashysky				
Sandstone	37 m (70%)	74 m (56%)	69 m (40%)	45 m (39%)
Siltstone	15 m (30%)	49 m (37%)	69 m (40%)	49 m (42%)
Clay, marl, limestone	None	10 m (7%)	28 m (20%)	22 m (19%)
Sub-Domanik				
Siltstone	20 m (57%)	None	13 m (11%)	6 m (7%)
Clay, marl, limestone	15 m (45%)	41 m (100%)	109 m (89%)	84 m (93%)
Domanik				
Clay, marl, limestone	None	10 m (100%)	190 m (100%)	103 m (100%)
Rocks	**Krym-Saray No. 3**	**Tuymazy No. 138**	**Baltayevo No. 2**	**Kargaly No. 1bis**
Pashysky				
Sandstone	6 m (9%)	37 m (53%)	6 m (10%)	27 m (42%)
Siltstone	37 m (48%)	13 m (19%)	23 m (37%)	20 m (31%)
Clay, marl, limestone	33 m (43%)	19 m (28%)	33 m (53%)	17 m (27%)
Sub-Domanik				
Siltstone	None	None	None	None
Clay, marl, limestone	26 m (100%)	24 m (100%)	26 m (100%)	15 m (100%)
Domanik				
Clay, marl, limestone	44 m (100%)	33 m (100%)	29 m (100%)	25 m (100%)

CLASSIFICATION OF THE LOWER FRASNIAN SEDIMENTS IN THE VOLGA-URAL PROVINCE: THEIR ORIGIN AND ORGANIC CONTENT

Lithology and Organic Content in Pashysky Sediments

Although the Pashysky sediments are characterized by considerable lithologic variety, sandstones and siltstones are most common. These sandstones are light-gray (occasionally almost white), fine- or medium-grained rocks which react either weakly or not at all to hydrochloric acid (HCl). The grains are angular to sub-angular; few grains are smaller than 0.10 millimeters (mm) and few larger than 0.25. Quartz is the major mineral component. Some muscovite, and occasional grains of hornblende, tourmaline, and zircon occur. The quartz grains may be imbedded in a siltstone matrix or may be cemented by tiny grains of carbonate rock or silica. The carbonate cement is locally prominent but extends over areas including only 5 to 20 quartz grains. Siderite is the most common carbonate cement; calcite cement also occurs. A few layers contain enough carbonate cement to be considered calcareous sandstones.

The texture of the sandstones varies. In several areas, the sandstones are massive and show no trace of layering, although these rocks fracture along roughly parallel surfaces. Small reddish spots, 1 or 2 mm in diameter, are present on a light-gray background. Some samples also contain short black streaks from 0.3 to 1.0 centimeter (cm) long which consist of argillaceous-carbonaceous material. The streaks are lenses with an irregular curvature or a wavy form, varying from one streak to another. They are roughly parallel to, but occasionally cross, the bedding, thus making the bedding and fracture patterns frequently complex. The dark material contains opaque, black carboniferous material which may be coalified plant remains or amorphous petroleum hydrocarbons (?). Streaks of silica are occasionally observed within the argillaceous material. It is characteristic that sandstones with this irregular fracture and bedding pattern are enriched with irregularly distributed argillaceous material.

No faunal remains were seen in a micro-

scopic examination of the sandstones: although such remains are observed occasionally in limestone. Plant remains consist of relatively large fragments of coal, spores, and fragments of plant tissue. The sandstones are saturated with petroleum in many areas, smell of it, and are dark in color.

The CO_2; organic carbon; and elemental iron, manganese, and phosphorus contents of the Pashysky sandstone were determined in order to establish its quantitative chemical characteristics (table 2). The $FeCO_3$ was taken as a measure of CO_2 concentration. This procedure of course, gives exaggerated values for carbonate concentrations, for $CaCO_3$ is present as well as $FeCO_3$. The exaggeration, however, does not exceed 5 percent of the total carbonate content, as determined by comparing the molecular weights of $FeCO_3$ and $CaCO_3$ which are in a ratio of 100 to 115.8.

high-carbonate sandstones. From these, it is assumed that much ankerite is present in the cement.

Siltstones dominate the Pashysky lithology as much as the sandstones do. Although their petrographic characteristics are highly variable, they may be grouped into two classes, homogeneous and layered. The homogeneous (or massive) siltstones may be represented by rocks grading from sandstone to clay. Microscopic examination revealed that regular silt and very fine rock flour, which in some cases forms homogeneous aggregates, dominate the textural composition of the rock. The flour constitutes a minor component in the coarse-grained siltstones (median: 0.07 or 0.08) and occurs as very thin veins of cement. It fills relatively large spaces between the grains of medium-textured siltstones and becomes a matrix in which quartz 0.02 or 0.03 mm in diameter are embedded.

TABLE 2. Chemical composition of Pashysky sandstones (%)

Sequence and Rock	Carbonates Computed from CO_2	Organic C	Fe	Mn	P	Remarks*
1. Ardatovsk						
Average	1.57	0.08	0.62	0.013	0.013	Average for 3 samples
Carbonate enriched	14.89	0.26	None	None	None	
2. Narysh						
Average	0.98	0.15	0.51	0.01	0.013	Average for 3 samples
Enriched with organic matter	1.62	0.91	None	None	None	
Carbonate enriched	10.0	1.12	None	None	None	

* The samples indicated were only those analyzed for Fe, Mn, and P; this applies to all similar tables.

Table 2 shows that the Ardatovsk and Narysh sandstones are indistinguishable. These rocks contain little carbonates, organic matter, and heavy minerals, but considerable iron. It is inferred that the iron occurs in the carbonate cement and that the rock contains virtually no clastic iron minerals. The elemental iron concentrations (calculated from carbonate concentrations) are 1.28 percent for the Ardatovsk sandstones and 1.06 percent for the Pashysky sandstones. Comparison with carbonate concentrations (calculated from CO_2 concentrations) shows that siderite is the only carbonate present.

A change in the general appearance and color of the siltstone accompanies the change in the relationship between silt and flour. The coarse-grained siltstones, like the sandstones, are generally light gray or nearly white. Occasionally, darker gray, reddish, or greenish shales appear. The finer grained siltstones are darker. Thus, the massive, homogeneous siltstones become darker and brighter as the average diameter of the component quartz grains decreases.

The layered siltstones may be parallel-bedded, lenticular, or cross bedded. The layers of silt

TABLE 3. Composition of carbonates in very calcareous sandstones

Well and Sample Number	Insoluble Residue	$FeCO_3$	$CaCO_3$	$MgCO_3$	Excess MgO
Sernovodsk No. 3, Sample 1997	80.16	4.82	10.85	1.90	0.97
Berezovka No. 8, Sample 891	92.26	1.71	4.31	1.94	None
Tuymazy No. 138, Sample 3870	88.96	2.10	6.30	1.55	None
Tuymazy No. 510, Sample 4246	91.94	2.03	5.07	None	0.64
Tuymazy No. 138, Sample 4011	90.40	1.82	5.06	2.13	0.15
Tuymazy No. 138, Sample 4006	90.00	1.98	5.06	2.20	0.26

Table 3 shows the quantitative relationships of the various carbonates in several samples of

and flour are parallel in the parallel-bedded siltstone. The individual laminae of silt and

flour are either perfectly even or possess a fine undulation. The thickness of the individual layers in the coarse-grained siltstones ranges from 1 to 2.5 mm. The thickness of the flour laminae which divide the silt laminae is a fraction of a millimeter. The silt laminae in the medium-grained siltstones are approximately the same thickness as the rock-flour laminae (between 0.2 and 0.5 mm). The laminae of rock flour are thicker than the silt laminae in the fine-grained siltstone. The number of laminae per centimeter (measured perpendicular to the bedding planes) varies considerably. As the silt layers increase in size, the rock-flour layers decrease. This variation in the flour (actually clay) laminae gives the rock a layered appearance both mega- and microscopically. The light layers, rich in quartz, alternate with dark layers, rich in clay.

The rock-flour laminae frequently exhibit thickness variation in silt specimens broken along the bedding plane. Occasionally a layer of clay will not extend entirely across a core cross section. Changes in the thickness of the wavy flour layers are especially striking. The sharpness of boundaries between successive layers varies from distinct to indistinct. The indistinct layering is most common in the lighter silts. The average thickness of these silt layers is between 0.05 and 1.5 mm. They are separated only by darker layers rich in argillaceous material.

The lenticularly bedded silts are distinguished from the parallel-bedded silts by means of the lower clay content in their lenses. These silts are typically fine grained, but medium-grained silts frequently have lenticular bedding. It is also characteristic that the lens thickness varies over distances less than the diameter of a 4 or 5 cm core. The laminae can increase to a thickness of 3 mm or more, decrease to nearly 0, or change into tiny light spots on a dark argillaceous background. The silt may replace argillaceous flour or may be replaced by this flour. Lenses with thicknesses ranging from 0.5 to 0.8 cm may taper to 0 over a horizontal distance between 0.5 and 2 cm. The lenses of quartz silt are generally thicker than the alternating argillaceous laminae in medium-grained siltstones. This relationship is reversed in fine-grained siltstone where the light quartz-silt lenses are embedded in a darker argillaceous matrix. The lenticular structure is particularly clear in such rocks.

Quartz-silt lenses are generally horizontal. In many cases, they undulate about a horizontal plane. Where the flexure of the lenses is considerable, the lenses tend to merge and are much thicker. Space relationships are made more complicated by local erosion which results in "unconformities" and cross bedding on a minute scale. The angle between two successive layers may be as great as 25°. Both undulating and cross bedded structures are accompanied by shear planes in the argillaceous flour. The complexity of the structure is, in part, due to deformation caused by movement along these shear planes within a sedimentary deposit which is petrographically complex from the start. The microscopic examination of several thin sections cut at angles oblique to the bedding revealed overthrusting within the folded lenticular structure. The distortion, stretching, and fracturing of oölite in iron deposits within the Pashysky is another example of this deformation [24].

Crossbedded siltstones, like the lenticularly bedded siltstones, are especially common in medium-grained sediments. The relationships between quartz silt and argillaceous flour are extremely irregular. Layers of argillaceous flour have a very limited horizontal dimension (2 or 3 mm). They are undulating, irregularly bent, bunched together, distributed sporadically, and occur in such a great variety of shapes and attitudes that the rock reminds one of dough. In some cases, the rock shows signs of slumping along the bottom of the basin of deposition. Sinuous small laminae truncate other laminae, and other relationships of this type add to the complexity of structure.

The activity of burrowing organisms, mainly worms, contributed to the complexity of the cross bedded structure, particularly noticeably in parallel-bedded and lenticular siltstones. In some specimens, the horizontal beds are punctured by tubes 2 or 3 mm in diameter and roughly circular in cross section. These may be either perpendicular or oblique to the bedding; are filled with greenish clay which is identical with the diagenetic product of argillaceous rock flour; and generally occur in groups of 3, 4, or 5. The determination of the length of the tubes was prevented by the smallness of the cores, but it has been asserted that they are longer than 3 or 4 cm. Rounded-tube ends have been found, however.

In fracture surfaces paralleling bedding planes in clays white circles or oval spots, tubes 1 to 1.5 mm in diameter and as much as 1 cm long, which are filled with quartz silt, occur. These structures are generally many in number. They are simply quartz-filled burrows and, in some cases, coalescing burrows, probably made by worms also.

The mineralogy and chemistry of the Pashysky siltstones are rather uniform. The siltstones are essentially composed of sharply angular quartz fragments; occasional grains of chert and opal; erratically abundant muscovite; some glauconite; the heavy minerals epidote and chlorite (?); and, according to the literature, garnet, zircon, rutile, anatase, and mica. Incomplete microscopic analyses of the argil-

laceous flours revealed particles of hydrated lepidomelane, which has a set of optical properties similar to those of muscovite. The epigenetic minerals include iron hydroxides, pyrite, glauconite, siderite, and leptochlorite.

The iron hydroxides frequently cause an uneven dark color in the clays; however, they also form yellow concretions within the clay. Pyrite occurs as small spheres ranging from 0.2 to 0.3 mm in diameter. It also forms concretions, aggregates, and amorphous films similar to the amorphous carbonaceous material in the Pashysky. Pyrite cubes are sometimes encountered. The various types of pyrite particles are more abundant as the siltstone grains become finer. Both iron hydroxides and pyrite are more abundant in the reddish siltstones. Glauconite generally occurs as isolated green grains with sharply defined common orientations in dark-red and greenish siltstones. They are sharply angular and irregular in shape, thus indicating their authigenic origin.

Siderite and leptochlorite, occurring together, are very diagnostic for the Pashysky sequence. Siderite most commonly occurs as rhombohedral crystals between 0.02 and 0.03 mm in diameter. These crystals are isolated individuals or aggregates between quartz grains. Siderite also occurs as nodules, either cementing siltstone particles, or wrapped about pyrite. The cemented type is an amorphous or roughly radial matrix in which siltstone particles are embedded. These are generally 1 mm in diameter, and are sometimes dark red due to oxidation. The pyrite nodules vary from angular to spherical. The nucleus consists of a very fine-grained siderite matrix containing many black grains of pyrite. The outer portion of the nodule is composed of radially disposed siderite wedges. Thin sections cut from this type of nodule exhibit a dark cross. They rarely contain clastic particles. Pyrite was not observed outside the nodules in any thin sections examined. Siderite nodules and stains are locally abundant. Some specimens have a rather densely spotted surface due to siderite.

Two types of oölitic siderite concretions occur. One appears as dark-red spots no longer than 1 mm in thin section. They consist of concentric rings of dark iron oxide and lighter siderite. The second type consists of comparatively large grains of recrystallized siderite. In this type, the dark iron oxides outline the pre-recrystallization shape of the grains.

Both large and small siderite nodules are especially characteristic of the Pashysky siltstones and constitute distinct layers in core samples. In some (extreme) cases, the siderite is very fine grained and quite pure. However, tiny grains of quartz silt and a yellow-green substance which apparently is leptochlorite contaminate it. In some instances, the leptochlorite is amorphous and, in others, it appears as a flaky or fibrous structure under crossed nicols. Its birefringence is very weak. Larger recrystallized grains of siderite are generally associated with increased amounts of clastic quartz.

Most frequently, leptochlorite is intimately associated with siderite. However, leptochlorite forms dark-green lenticular inclusions which are widespread in the Pashysky sequence. It may occur as more or less sharply delineated oölites with a clearly discernible concentric structure formed by alternating layers of leptochlorite and dark iron oxide. Some oölites preserve this structure in spite of their squeezed lenticular shaped and twisted and stretched forms.

Siderite is the predominant, and frequently the only, carbonate in the Pashysky siltstones. It is a rare specimen in which calcite is a significant component.

What little organic matter is contained in the siltstones consists entirely of plant fragments which may be large or very small. Spores and spore fragments appear as bright-red bands and spots in the argillaceous rock flour. Faunal remains are rare; brachiopods (Lingula, and others) are more abundant as the concentration of calcium carbonate increases.

Table 4 shows that the quantity of certain components are similar for the Ardatovsk and Narysh siltstones. A comparison of these siltstones with the Pashysky sandstones indicates that the carbonate content and, therefore, the degree of sideritization are very nearly the same in both types of rock. The chemical characteristics are less the same. For example, the organic-carbon content of the siltstones is between 0.39 and 0.41 percent, which is considerably higher than the 0.08 to 0.15 percent in the sandstones. The difference between the iron concentrations is even sharper. The siltstones contain 2.24 percent iron and the sandstones 0.62 percent. The manganese concentrations are 0.034 and 0.013 percent, respectively, and the phosphorous concentrations are 0.0444 and 0.044 and 0.013 percent. The quantitative relationship of siderite in high-carbonate siltstones and other carbonates in these rocks are shown in table 5.

The Pashysky contains oölitic chamosite (iron) ore, argillite, marl, and limestone, as well as the components already described. The oölitic iron ores are widespread in the Volga-Urals and are frequently encoutered in drill holes. Miropolsky's [24] recently published summary and our data show that these iron ores are localized 1) at the base of the Ardatovsk (a group of thick and extensive iron deposits in the Tuymazy area); 2) in the middle the Ardatovsk

TABLE 4. Concentrations of organic carbon, carbonates, iron, manganese, and phosphorus in siltstones of Pashysky age

Sequence and Rock	Total Carbonates, computed from CO_2	Organic C	Fe	Mn	P	Remarks
1. Ardatovsk						
Average	1.45	0.41	2.24	0.034	0.044	7 samples
Enriched with organic matter	1.16	1.20	None	None	None	
Carbonate enriched	16.72	0.49	None	None	None	
2. Narysh						
Average	1.32	0.34	2.14	0.023	0.04	5 samples
Enriched with organic matter	1.23	1.22	None	None	None	
Carbonate enriched	16.90	0.16	None	None	None	

TABLE 5. Composition of carbonate components of Pashysky siltstones (%)

Well and Sample Number	Total Carbonates	$FeCO_3$	$CaCO_3$	$MgCO_3$	Excess MgO
Borovka No. 3, sample 1822	31.37	29.76	1.00	0.61	1.11
Borovka No. 3, sample 2172	4.85	3.60	1.25	None	0.98
Borovka No. 3, sample 2167-2170	5.58	4.58	1.00	None	0.71
Borovka No. 3, sample 2166	4.30	3.55	0.75	None	0.49
Borovka No. 3, sample 2143	5.05	4.29	0.75	None	0.64
Borovka No. 3, sample 1888	24.75	23.75	1.00	None	0.90
Borovka No. 3, sample 2124-2126	5.15	4.24	0.91	None	0.35
Kostychi No. 4, sample 1042	25.05	7.05	15.24	2.76	1.57
Kostychi No. 4, sample 1046-1047	4.56	None	4.56	None	0.16
Kostychi No. 4, sample 1104	56.12	13.22	41.06	1.84	5.24
Yerykly No. 5, sample 2475	4.03	2.53	1.50	None	0.54

near Shugurovo and Sugushny; 3) in the upper Ardatovsk, near Shugurovo; 4) in the lower Narysh, near Shugurovo and in Krym-Saray Well No. 3 and Tuymazy Well No. 138; 5) in the upper Narysh, near Romashkino, Baltayevo Well No. 2, and Kargaly. The Pashysky is rich in iron in the eastern third and to the north of the cross section, but the few samples examined are not enough to indicate the degree of mineralization continuity.

The iron ores consist of hydrogoethite, chamosite, and siderite. Oölites range from 0.3 to 1.5 mm in diameter. Some oölites have a concentric structure; others a radial-fibrous structure. The oölites are generally composed of iron hydroxides, but the outer layers of concentric oölites are frequently siderite. The cement contains relatively large fragments of silt. Quartz may constitute as much as 90 percent of the light fraction of the cement; a negligible amount of opal, feldspar, and muscovite may also be present. The heavy fraction, according to Miropolsky [24], may consist of epidote, zoisite, zircon, biotite, garnet, titanite, anatase, rutile, picotite, tourmaline, and corundum. The authigenic minerals are represented by pyrite.

The chemical composition of these iron ores is given in table 6.

The metallic iron content for one sample is 28.67 percent and the manganese content is 0.12 percent. Values for the other four samples are as follows: sample 2, 40.26 and 0.003; sample 3, 22.64 and 0.054; sample 4, 23.39 and 0.069; and sample 5, 20.10 and 0.11, respectively. Even the highest concentrations are characteristic of low-grade ores.

Argillaceous sediments occur as a minor component in all drill holes, generally in the upper Ardatovsk and Narysh sequences. These sediments are dense and massive, or weakly layered under microscopic examination. They are greasy; react weakly to HCl; and are gray and frequently red, chocolate-brown, or greenish. Microscopic examination reveals that the greater portion of these sediments consists of dirty-yellow pelitic mass which is composed of microcrystalline or oriented fibrous aggregates. Rateyev has shown that this mass is kaolin or kaolinic hydrated muscovite. Flakes of muscovite are also present. Inclusions in the pelitic matrix are quartz grains 0.01 to 0.04 mm in diameter and aggregates of rounded or cubic

TABLE 6. Chemical composition of Pashysky iron ores (%)

Sample and Locality	H_2O (hygroscopic)	Loss During Heating	SiO_2	Al_2O_3	Fe_2O_3	FeO
Well No. 5, Shugurovo; lower layer, oölitic ore	0.92	19.85	14.97	13.28	3.29	33.81
Separate oölites, same deposit	3.15	8.88	27.31	1.83	19.86	33.75
Same locality, second ore bed from bottom	1.18	13.58	38.78	12.11	2.79	26.53
Oölitic ore, Well No. 3, same locality	3.63	7.81	40.21	11.72	14.76	16.76
Oölitic ore, Well No. 3	3.41	10.54	43.50	10.07	15.02	12.29

Sample and Locality	TiO_2	Cr_2O_3	MnO	CaO	MgO
Well No. 5, Shugurovo; lower layer, oölitic ore	0.37	0.15	0.15	8.48	3.19
Separate oölites, same deposit	0.55	0.33	0.004	0.51	3.68
Same locality, second ore bed from bottom	0.57	0.13	0.07	0.54	1.80
Oölitic ore, Well No. 3, same locality	None	Trace	0.09	1.20	2.17
Oölitic ore, Well No. 3	None	Trace	0.14	1.08	1.21

grains of pyrite. Reddish translucent films of amorphous organic matter are abundant. Carbonate minerals vary from fine silt to pelite and frequently give the sediment the appearance of calcareous clay or even marl. Lenses and spots of chamosite occur in some specimens of lime-free clay. Faunal content includes widely scattered Lingula, Estheria, and assorted pelecypod fragments and clearly identifiable sponge spicules, as well as elongated fragments of calcite similar to sponge spicules.

A high carbonate content is characteristic of the gray argillaceous sediments. The green and red clays are virtually carbonate-free. A high quartz-silt content is diagnostic for the Pashysky clays. There is reason to believe that silt-free clays do not occur in the Pashysky sequence.

The amount of argillaceous material in the various sediments of the Pashysky is shown in table 7. The Ardatovsk and Narysh clays contain little carbonates but more iron, manganese, phosphorus than the siltstones and sandstones. The organic content of the clays is similar to that of the siltstones. It ranges from 0.34 to 0.41 percent in the former and from 0.36 to 0.41 in the latter. In some clay samples, the organic content was found to be as high as 5.68 percent. The highest concentration in siltstone samples was 1.22 percent. The average concentration of organic matter in the clays is 0.63 percent; the average concentration in the siltstones is 0.4 percent.

Table 8 shows that calcite is the dominant carbonate mineral in the Pashysky. Carbonate rocks, including marl, argillaceous limestone, and pure limestone, generally occur in all cores taken along the cross section. They constitute, however, a smaller proportion of the total sediments than do the argillaceous rocks. They are most significant in the upper Ardatovsk where they are 0.5 to 3 meters (m) thick, alternating with clays and siltstones. The carbonates seem to have been deposited as isolated lenticular beds, some of which are areally extensive; thus, it is impossible to correlate them. Carbonates also occur in the lower, middle, and upper Narysh. Because the carbonate beds in the uppermost Narysh have a uniform high electrical resistance, their upper surface is used to mark the Pashysky-sub-Domanik contact. If these beds can be stratigraphically correlated over a wide area, they will be the oldest carbonate beds in the lower Frasnian of the Volga-Urals to extend uniformly over some distance.

TABLE 7. Average concentrations of certain elements in Pashysky clays (%)

Sequence and Rock	Carbonates computed from CO_2	Organic C	Fe	Mn	P	Remarks
1. Ardatovsk						
Average	1.44	0.38	5.91	0.065	0.08	4 samples
Carbonate enriched	20.00	0.36	None	None	None	
Enriched in carbonates and organic matter	19.33	5.68	None	None	None	
2. Narysh						
Average	1.27	0.41	6.56	0.025	0.09	2 samples
Enriched with organic matter	0.49	2.30	None	None	None	
Enriched with carbonates and organic matter	18.28	1.65	None	None	None	

TABLE 8. Composition of carbonates in Pashysky clays (%)

Well and Sample Number	Total Carbonates computed from CO_2	$FeCO_3$	$CaCO_3$	$MgCO_3$	Excess MgO
Borovka No. 3, sample 2163	29.85	0.45	29.40	None	1.24
Kostychi No. 4, samples 1089-1091	19.15	2.42	16.73	None	1.24
Tuymazy No. 138, sample 3824	9.66	0.79	8.87	None	0.45
Tuymazy No. 138, sample 3876	47.42	2.82	44.60	0.33	1.13
Sernovodsk No. 3, sample 1995	6.87	5.37	1.50	None	0.98
Baltayevo No. 2, sample 4541	11.83	3.72	8.11	1.00	1.36

The petrography of the Pashysky carbonates is relatively simple. Limestones are dense, gray or dark-gray rocks in hand specimen; their crystal texture is fine or variable, occasionally pelitic; they are not layered; and they include variable amounts of argillaceous material. The limestones contain aggregates or individual small and large brachiopods.

Microscopic examination indicates that the limestone may be composed of shell fragments, or may be microgranular with organic matter or pelitic. The shell-fragment limestones are most common. They are composed of large (as much as 1 mm) and small brachiopod and crinoid fragments, with minor amounts of bryozoan, ostracod, foraminiferal, and algal remains. The algal remains consist of intricately intertwined thin tubes which can be found with other calcareous detritus, or attached to and covering brachiopod shells. The shell fragments are strongly cemented together, but recrystallization of the calcium carbonate is uneven. Occasionally, some dolomite rhombohedra are observed. Shell fragments may be silicified. Pyrite occurs as tiny spots, as well as microscopic spheres, films, and aggregates. Films of organic matter are relatively common. Some quartz-silt grains are generally present and, occasionally, the quartz-silt content is great enough to reclassify the rock as a calcareous siltstone. The amount of organic detritus decreases sharply in these cases.

Recrystallization occurs mainly in the shell fragments, although the cement may also be recrystallized. Fine-grained limestone is uniformly recrystallized; most crystals are between 0.02 and 0.05 mm in diameter. The crystals are frequently rhombohedral, indicating dolomitization. Clastic material is virtually absent; if present, it is pelitic.

The pelitic limestones are light gray, but may be nearly black in some cases. They are dense, fracture conchoidally, and occasionally contain brachiopods. Microscopic examinations revealed its cryptogranular structure and small zones of more advanced recrystallization. Many tiny grains of pyrite are present, but quartz is absent.

The few limestone samples collected were not enough to indicate vertical lithologic uniformity. However, enough limestone was collected in two instances to indicate strong vertical

variation. The first was a dark-gray (almost black), nonfossiliferous limestone with films of argillaceous-sapropelitic material along bedding planes. The limestone layers are relatively thick and consist of comparatively large irregular or elongated lumps of $CaCO_3$. The lumps are either recrystallized crystals or crystal aggregates. The argillaceous-sapropelitic material is composed of films or flakes of black or dark-red organic matter embedded in argillaceous matter. This material separates layers of calcareous lumps and occasionally converge to pinch out the carbonate layers. In general, the structure is similar to the large-scale structures in Black Sea sediments. These similarities, however, are superficial and do not indicate similarities in physical or chemical environments. The second (from Vaitugan) is a dark-gray fine-grained limestone megascopically. Microscopically, however, it is an agglomeration of irregularly bent, approximately cylindrical bodies as much as 0.5 mm long and 0.05 mm thick. They are packed quite densely; the spaces between them are filled with a dark-brown argillaceous material. These "sausages" are tiny pieces of recrystallized $CaCO_3$, apparently coprolites.

The concentration of organic carbon, iron, manganese, and phosphorus vary inversely with the $CaCO_3$ concentration (table 9), in accordance with the diluting effect of the carbonate. Nevertheless, 13 of the 61 carbonate-rock samples analyzed (more than 20 percent) showed a sharp increase in organic matter. This is twice the number of argillaceous and siltstone samples showing such an increase. These anomalous organic contents raise the average organic content to 1.95 percent in Pashysky marls and to 0.69 percent in limestones of the same age. Table 10 shows the significant variation in the degree of dolomitization in these limestones.

The Depositional Environment for Pashysky Sediments in the Volga-Urals

In discussing the depositional environment for Pashysky sediments in the Volga-Urals, two fundamental elements must be considered: 1) the relation of Pashysky sediments to other lower Frasnian sediments deposited on the Russian platform and 2) the paleontological and mineralogical characteristics of the Pashysky sediments.

The stratigraphic position of the Pashysky sediments in relation to other lower Frasnian deposits is shown on a lithological map (fig. 2) compiled by the geologists of GEOKHI [Tr.: geochemistry section] and VNIGRI [Ed.: All-Union Petroleum Scientific Research-Geological Re-Search Institute]. The essential characteristics

TABLE 9. Average concentration of selected elements in carbonate rocks (%)

Sequence and Rock	Total Carbonates computed from CO_2	Organic C	Fe	Mn	P	Remarks
1. Ardatovsk						
A. Marl						
Average	44.42	0.36	3.20	0.035	0.125	2 samples
Enriched with organic matter	50.85	2.84	None	None	None	
B. Argillaceous limestone						
Average	86.1	0.21	1.96	0.10	0.03	1 sample
Enriched with organic matter	74.43	3.92	None	None	None	
C. Limestone						
Average	96.3	0.19	1.70	0.07	0.04	2 samples
2. Narysh						
A. Marl						
Average	58.40	0.69	4.75	0.10	0.16	2 samples
Enriched with organic matter	65.24	5.64	None	None	None	
B. Argillaceous limestone						
Average	81.4	0.22	1.94	0.035	0.05	2 samples
Enriched with organic matter	82.4	1.91	None	None	None	
C. Limestone						
Average	95.2	0.15	None	None	None	

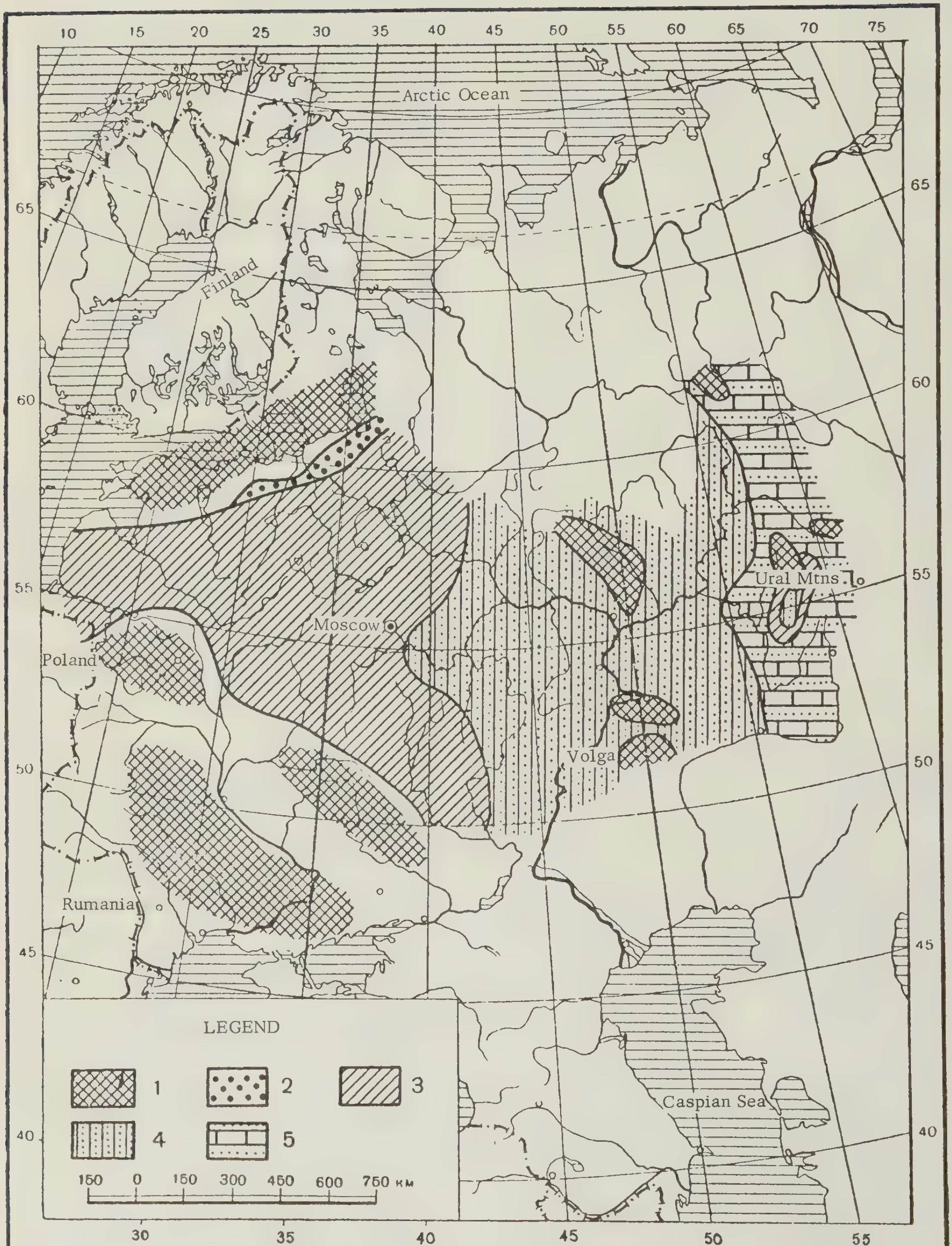

FIGURE 2. Lithologic-facies map of lower Frasnian (Pashysky-Kynovsk) deposits
(1) eroded region; (2) continental sediments; (3) continental sandstone and marine sandy siltstones; (4) marine silty sandstones; and (5) marine calcareous siltstone.

TABLE 10. Composition of selected carbonates (%)

Sample and Rock	Total Carbonates	Dolomite	Calcite	Excess MgO	Excess CO_2
Kargaly sample 4376, dolomitic marl	50.72	34.45	16.27	None	0.81
Berezovka No. 8, sample 896, marl	30.32	3.15	27.17	0.76	None
Borovka No. 3, sample 2123, limestone	93.25	4.33	88.92	None	0.09

of the various facies are shown clearly on the map.

A narrow band of continental clastics extends along the northern portion of the map. A broad zone of arenaceous-argillaceous sediments, with sporadic occurrences of marine fauna, lies to the south and east of this band. The map authors consider this an area of unstable marine conditions (repeated transgressions and regressions). These conditions are reflected in the alternation of marine and continental sediments in the cross section. A band of siltstones and sandstones, with minor clay, runs from somewhat east of Moscow to the Urals foredeep. A few limestone beds occur in this once stable area. Fossils are not generally abundant, but are more abundant here than in the northern zone. The sandstones and siltstones of the Ural foredeep are replaced by marine siltstones and limestones on the flanks of the Urals. Thus, the Pashysky sequence represents a broad periphery of a zone of cratonic deposition.

A meager fossil population and the almost complete absence of limestones are two distinguishing characteristics of the Pashysky. Abundant marine life is recorded in only a few beds of gray limestone. The carbonate facies contain abundant brachiopods (Schizophoria, Lingula), crinoids, foraminifers, pteropods, and bryzoans, as well as calcareous algae. These indicate that depth of deposition was less than 50 m. The fauna in the Pashysky clays is sparce. Occasional Lingula, bivalves, and ostracods were found although these have not been previously recorded in the literature. Siltstones and sandstones (except for the most calcareous) are virtually barren. Worm tubes have been observed in the siltstones, a sign that these sediments were not completely devoid of living creatures. Brachiopod, ostracod, and crinoid fragments occur in the very calcareous siltstones and sandstones which constitute a transition from the arenaceous sediments to the organic limestones. These very calcareous siltstones and sandstones, however, do not usually occur in the Pashysky. The near-absence of fossils in the Pashysky sediments is especially obvious when compared with the abundant and varied faunal remains in the carbonates of the Shchigry basin to the east. The little carbonate material in the sandstones, siltstones, and clays of Pashysky age is siderite; the calcite is generally restricted to marl and limestone deposits.

It is possible that the scarcity of fossils and the extremely low limestone content are secondary characteristics of the Pashysky sequence which are dependent upon the solution and removal of carbonates from shell deposits, as is the case in the Paleogene Buchaksk and Karkovsk sediments in the Ukraine. However, in the Pashysky sequence, the scarcity of fossils and the low limestone content is consequent upon the high siderite and chamosite content. The fact that the chemistry of the Pashysky sediments is strongly influenced by the presence of siderite and chamosite has been noted by G. I. Teodorovich [41]. Both siderite and chamosite develop in environments of little or no limestone; therefore, the extremely low calcium carbonate content of the clastics of Pashysky age is a primary characteristic.

The environmental conditions under which Pashysky sediments were deposited varied. The organic and pelitic-organic limestones, marls, fossiliferous clays, massive homogeneous calcareous siltstones, and some of the lenticular-laminar siltstones were probably laid down in shallow marine waters. The massive homogeneous white sandstones are, in part, beach deposits; perhaps large sandy islands in the basin of deposition. The fossil flora in the sandstones and the abundant spores especially in the medium- and fine-grained siltstones indicate that these large sandy islands were covered with vegetation.

Shallow tidal or lagoonal basins occurred among the islands and also in the interior of some of the larger islands. The water in these basins were considerably less saline than in other parts of the Shchigry basin. The sediments deposited in this environment were dominated by limestone-free silts that contain a very meager and repressed ostracod, Lingula, and bivalve population. In the deeper basins, where water motion was negligible, silts were deposited as regularly laminated sediments. Worms, abundant in more shallow basins as well as in the near-shore areas, contributed to the irregular arrangement of the sediments by passing silts through their digestive tracts as they burrowed. Oölitic iron ores were deposited, in part, in the lagoonal or tidal basins and also in near-shore areas. Thus, the eastern portions of the Russian platform had a complex environment during Pashysky time.

Numerous islands probably dotted the

shallow sea in which Pashysky sediments were deposited. Some of these islands were sand bars that supported much vegetation; others consisted of basement rock. Figure 2 shows the location of some of these islands on which consolidated basement rock was exposed. One rather large island was situated north of Kazan, another extended southeastward from Samarsk Bend to the vicinity of Pokrovka, the great Pugachev uplift was farther south, and a large island was situated in the area which is now the southern portion of the Ufimskoye plateau. Apparently, a large island or several small ones were located in the vicinity of Ulyanovsk; this is indicated by the very small thicknesses of Pashysky sediments northwest of Samarsk Bend. Sandstone, siltstone, pelite, and limestone were deposited cyclically in response to the expansion and contraction of the large islands, their basins, and lagoons which were caused by crust oscillations. Limestone deposition was particularly strong at the end of Ardatovsk time, indicating a major marine transgression. The overall character of the sea remained unchanged during Pashysky time, except for minor shoreline oscillations.

The terrigenous and authigenic minerals in Pashysky sediments are clues to the physical-geographic conditions prevailing during early Frasnian time. Pashysky sandstones and siltstones generally contain 90 percent or more quartz with muscovite flakes. The heavy-mineral fraction consists of a few highly stable minerals including pyrite, rutile, zircon, garnet, anatase, and, quite rarely, biotite and epidote. The pelitic fractions of the siltstones and clays, according to Rateyev, consist of very kaolinitic hydromuscovite and kaolin. Siderite and chamosite, occurring both as low-grade iron deposits and as scattered individual minerals, are the most common authigenic minerals. The low-grade iron deposits extend along the belt in which consolidated basement rocks were exposed and eroded; they form peripheries about the Samarsk, Ufimskoye, and Timansky uplifts. The oölitic ores are encountered at Berezovka near Samarsk; in the vicinity of the Ufimskoye plateau; and in a series of drill holes at Shugurovo, Krym-Saray, Tuymazy, and Baltayevo to the west. These ores are also found in the Karatau ranges to the east, to Kizel to the northeast (the Pashysky red ores), and in the central Timansky ridge. The lithologic uniformity of the Pashysky clastics indicates that these authigenic minerals were the result of processes different from those which resulted in deposition of the sandstones and siltstones. Some of the iron minerals entered the basin in solution, others as hydrogoethite suspensions.

The mineral assemblage in the Pashysky sediments show that the islands and mainland which served as a source of clastic materials existed in a moist, probably warm climate, at least in the eastern half of the Shchigry basin. The consolidated basement rocks outcropping on islands and mainland were completely eroded. These conditions gave rise to very uniform sandstone, siltstone, kaolin, and kaolinitic mica deposits, as well as the precipitation of iron minerals from solution and hydrogeothite suspension.

The small amount of organic matter in the clays, sandstones, and siltstones is striking. The average concentration of organic carbon is between 0.3 and 0.6 percent. The concentrations increase to 6 percent in some individual clay and, especially, marl beds. Perhaps these localized high concentrations of organic matter are due to the large amounts which must have accumulated in the lagoonal and tidal basins where abundant algal growth may have existed.

Petrographic Characteristics and Origin of the Sub-Domanik Sequence

The lithology of the sub-Domanik sequence, unlike that of the Pashysky sequence, is dominated by clays and marls; subordinate sandstones, siltstones, limestones, and iron ores are present in the sequence. The sub-Domanik sediments, however, are qualitatively similar to the Pashysky sediments. This is especially true for the sandstones and siltstones best developed in the Samarsk uplift where the sub-Domanik overlies unconformably the Middle Devonian. The siltstones, encountered as subordinate beds in all drill holes from Samarsk to Kargaly, resemble the Pashysky siltstones in mineralogy, color, and texture. Hand specimens taken from the sub-Domanik cannot be distinguished from those taken from the Pashysky. Table 11 shows that the sub-Domanik siltstones in the central and eastern portions of the cross section have the same chemical composition as the Pashysky siltstones. The quantity of organic matter in the sub-Domanik siltstones is slightly higher on the Samarsk uplift, even higher than the organic content of the Pashysky clays. This is probably due to the fact that the Samarsk uplift was an island of considerable extent.

The sub-Domanik clays also bear a strong resemblance to the Pashysky clays, although they are brighter in color. The clays in the lower sub-Domanik are greasy, massive or poorly layered, and flaky. They are bright green or gray green to chocolate brown. They do not effervesce with acid nor contain fossil fauna. The clays in the upper sub-Domanik are a uniform pale gray and effervesce with acid, indicating considerable $CaCO_3$. These clays also contain pteropods, Buchiola, Lingula, and other sub-Domanik forms. The mineral composition of the fines, studied by Rateyev, is the same as the mineral composition of the fines in the Pashysky clays; the kaolin component, however, is comparatively small and the kaolinitic hydromicas are replaced entirely by beidellitic hydromicas.

TABLE 11. Average concentrations of selected elements in Domanik sandstones and siltstones (%)

Rock	Total Carbonates computed from CO_2	Organic C	Fe	Mn	P	Remarks
1. Samarsk uplift						
Sandstone	0.62	0.17	None	None	None	
Siltstone, average	2.40	0.51	1.19	0.01	0.02	2 specimens
Siltstone enriched with carbonates	25.20	0.26	None	None	None	
Siltstone enriched with organic matter	0.05	1.51	None	None	None	
2. Borovka, Sernovodsk, Yerykly and Tukmakly districts						
Siltstone, average	3.86	0.17	2.31	0.03	0.03	1 specimen
Siltstone enriched with carbonates	38.62	0.06	None	None	None	
Siltstone enriched with organic matter	None	5.0	None	None	None	
3. Eastern portion of cross section (Krym-Saray, Kargaly)						
Siltstone, average	1.20	0.17	2.62	0.03	0.03	1 specimen

As yet, only clays with low carbonate content have been studied; it is possible that future investigations will reveal variations in the clay-mineral composition. Abundant pyrite, occurring as amorphous microscopic inclusions and strains, is characteristic of the sub-Domanik. clay resemble those of the Pashysky clays. An increase in calcium carbonate, however, is observed as the clays become more marllike. Concentrations of organic matter are greater in the clays, as they are in the siltstones, of the Samarsk uplift.

TABLE 12. Concentrations of selected elements in sub-Domanik clays (%)

Rock	Total Carbonates computed from CO_2	Organic C	Fe	Mn	P	Remarks
1. Samarsk uplift						
Clay, average	2.74	0.42	4.85	0.046	0.06	3 specimens
Clay enriched with organic matter	0.35	10.56	None	None	None	
Clay enriched with carbonates	21.23	0.33	None	None	None	
Clay enriched with organic carbon and carbonates	9.19	2.17	None	None	None	
2. Borovka-Tukmakly district						
Lower sub-Domanik clay	3.63	0.18	5.36	0.051	0.07	7 specimens
Upper sub-Domanik clay	24.76	0.60	None	None	None	
3. Krym-Saray-Kargaly district						
Clay, average	1.56	0.47	None	None	None	
Clay enriched with organic matter	0.16	1.36	None	None	None	

Table 12 shows that the concentrations of elements and compounds in the sub-Domanik

A distinctive type of low-grade oölitic chamosite ore occurs in the eastern third north of the

cross section at Tuymazy, Shugurovo, Romashkino, and Sugushny in the middle and upper Mikhaylovsk horizon. Miropolsky [24] writes, "All oölitic ores in the Mikhaylovsk horizon are microgranular. Their oölitic structures can be seen only under the microscope; they resemble argillites in hand specimen; their coloration is either greenish (green oölite ore) or brownish (chocolate oölite ore). Both types contain abundant shale .... the cement (in Tuymazy Well No. 396) contains between 30 and 35 percent iron. Most of the cement, however, consists of a gelatinous substance which is not affected by polarized light and flaky aluminous chamosite, which tends to cluster about the oölites. About 50 percent of the ore is composed of aluminous chamosite oölites. These oölites have a concentric structure, are generally rounded, and are from 0. 05 to 0. 4 mm in diameter. The terrigenous components, mainly silt, constitute no more than 20 percent of the ore. The more common components in the heavy fractions, in addition to diagenetic pyrite and hypergenetic hydrogoethite are magnetite and ilmenite, 22. 55 percent; zircon, 13. 85 percent; tourmaline, 3. 64 percent; titanite, 0. 52 percent; rutile, 0. 39 percent; epidote and zoisite, 0. 26 percent; hornblende, 0. 26 percent; picotite, 0. 13 percent; garnet, 1. 13 percent; and anatase, 0. 13 percent. The light fraction contains 94. 87 percent quartz, 2. 72 percent amorphous silica, and 2. 49 percent feldspar. Pyrite commonly occurs in the ore as small cryptocrystalline nodules. Both ore and associated minerals are uniformly colored by iron hydroxide. The Al_2O_3 content is 20. 47 percent; Fe_2O_3, 6. 17 percent; FeO, 14. 74 percent; elementary Fe, 15. 13 percent." Samples taken at other wells do not have the same composition. The quantitative relationship between oölites and chamosite cement, variation in the amount and texture of the terrigenous material, and the frequent occurrence of uniformly distributed siderite contribute to the differences in composition.

Carbonate rocks, mainly marls and partly argillaceous limestones, are confined to the upper half of the sub-Domanik sequence. One type of marl is light gray, plane or conchoidally fractured, and contains some microfossils. Its $CaCO_3$ distribution is uneven and occurs as nodules of irregular and indistinct outline. The rock is considerably dense and has an irregular hackly fracture where the nodules are very closely grouped together. Larger grains of recrystallized calcium carbonate are embedded in a carbonate-argillaceous matrix. These grains, varying in shape, are rhombohedral. They occur in aggregates in some instances. In general, organic remains are either very rare or absent; occasional fragments of pteropod or brachiopod shells are encountered. Pyrite is common. The other type of marl occurs most frequently in the Sernovodsk-Tukmakly area. It is a dark-gray rock which does not smell bituminous when broken. It is generally devoid of organic material, although it does contain shell fragments. The density of these marls is highly variable. Some exhibit a nodular structure. Large, irregular, rhombohedral calcium carbonate grains stand out more sharply in the second marl than in the first. Pryite is abundant.

The sub-Domanik limestones consist of pteropod and brachiopod shell deposits and thinly laminated fine-grained calcium carbonate in which large and generally rhombohedral dolomite fragments are embedded. At Berezovka, they contain much glauconite which gives the rock a greenish color. The average composition of the sub-Domanik marls and limestones is given in table 13.

Several samples of upper sub-Domanik marls and limestones contain higher hydrocarbon concentrations and fauna typical of the Domanik, indicating, perhaps, that these rocks are the first sporadic appearances of the Domanik. Unlike the Domanik sediments, however, they do not possess the characteristic bituminous odor and therefore must be sub-Domanik.

The degree of dolomitization of the 19 sub-Domanik marl and limestone specimens is shown in table 14. The degree of dolomitization varies inversely with carbonate content. The average dolomite content of the carbonate component in clays is 32. 8 percent; it is 17. 4 percent in marls and only 8. 6 percent in the argillaceous limestones. Excess magnesium oxide, derived from silicate rocks, is a function of the composition of clay minerals. Excess carbon dioxide, which occurs very rarely, may possibly indicate the presence of $FeCO_3$ in the $MgCO_3$ molecule.

The character of these marls and limestones indicate the gradual transgression of the early Frasnian sea. The sandstone-siltstone complex is replaced by an argillaceous-calcareous complex from west to east across the lithofacies map for the Pashysky. The marine transgression began with the deposition of argillaceous sediments over the Pashysky arenaceous sediments, and the argillaceous deposits were covered by marls - a classic example of marine transgression. However, the marl and clay contain large amounts of organic matter. These beds were deposited at some distance from the shore, and not near the shore, as were the Pashysky. This is an excellent example of what N. G. Vassoyevich terms "anomalous bedding".

Fine, strongly carbonate silts with Lingula, Buchiola, and many pteropods were deposited in areas east of the present Volga at the end of sub-Domanik time. There is no doubt that these sediments were deposited considerably below the lower limit of turbidity effects, and may,

TABLE 13. Average concentrations of selected elements in sub-Domanik marls and limestones (%)

Rock	Total Carbonates computed from CO_2	Organic C	Fe	Mn	P	Remarks
1. Samarsk uplift						
Marl, average	58.5	0.33	None	None	None	
Argillaceous limestone	86.59	0.55	1.20	0.02	0.03	1 sample
Limestone	96.98	0.11	None	None	None	
2. Sernovodsk-Tukmakly area						
Marl, average	49.2	0.59	4.44	0.04	0.06	3 specimens
Marl, enriched with organic matter	43.5	2.10	None	None	None	
Argillaceous limestone, average	78.22	0.46	2.20	0.055	0.05	2 samples
Argillaceous limestone, enriched with organic matter	72.50	5.07	None	None	None	
Limestone	91.30	0.21	None	None	None	
3. Krym-Saray-Kargaly district						
Argillaceous limestone	81.02	0.30	2.39	0.14	0.12	4 samples
Limestone	95.7	0.27	None	None	None	

TABLE 14. Degree of dolomitization of sub-Domanik carbonates (% dry rock)

Rock	Total Carbonates	Dolomite	Calcite	Degree of Dolomitization	Excess MgO	Excess CO_2	CO_2 Deficiency
Calcareous clay							
Tukmakly No. 9, sample 2566	27.10	15.48	11.62	57.1	None	0.15	None
Tukmakly No. 9, sample 2568	20.10	6.82	13.28	33.9	None	1.20	None
Borovka No. 2, sample 1828	26.11	7.21	18.90	27.6	0.28	None	None
Zolny No. 2, sample 1516	18.83	2.39	16.44	12.7	None	None	None
Marl							
Teplovka sample 682	42.50	9.82	32.68	23	None	0.15	None
Teplovka sample 680	57.24	8.79	48.45	15	0.54	None	None
Teplovka sample 264	59.18	7.50	51.68	12.6	0.18	None	None
Teplovka sample 266	59.26	8.72	50.54	15.0	0.11	None	None
Teplovka sample 685	55.75	None	55.75	0.0	None	None	0.13
Tukmakly No. 9, sample 2569	32.99	19.51	13.48	59	None	1.07	None
Borovka No. 2, sample 1823	49.20	4.53	44.67	9.2	0.60	None	None
Borovka No. 2, sample 1838	37.98	2.14	35.84	5.6	None	None	0.02
Argillaceous limestone							
Tukmakly No. 9, sample 2565	71.71	7.20	64.51	10.0	0.39	None	None
Tukmakly No. 9, sample 2570	73.89	7.52	66.37	10.1	None	1.15	None
Borovka No. 2, sample 1833	72.61	4.75	67.86	6.6	0.30	None	None
Borovka No. 2, sample 1856	82.40	0.66	81.74	0.8	None	0.71	None
Krym-Saray sample 3768	89.08	0.92	88.16	1.0	0.78	None	None
Krym-Saray sample 3772	80.74	60.18	20.56	74.5	None	None	None
Kargaly sample 4335	76.03	4.44	71.59	5.9	0.57	None	None

therefore, be analogues of Recent semipelagic sediments. The depths at which these silts were deposited, however, were far from those at which Recent semipelagics are found. But the vertical extent of the zone of turbidity in ancient seas was much less than it is in present-day oceans. The fine silts, therefore, could have been deposited at depths of 100 m or even less.

The clay-marl sediments deposited at the end of the sub-Domanik probably accumulated no lower than the belt between the middle of the continental shelf and the upper edge of the continental slope. Shchigry sediments in the central portions of the Moscow basin to the west were deposited in the central portion of the sea for which the sub-Domanik constitutes

a near-shore facies. Study of Shchigry sediments to the east may reveal further information of the depositional environment of the semipelagics.

Lithology and Origin of the Domanik Sediments

Everywhere in the Volga-Urals province, the Domanik consists of alternating bituminous limestones, argillaceous limestones and marls, and a few clay beds. The sequence contains no sandstone or siltstone. Gray, greenish, and reddish clays, similar to the greenish clays of sub-Domanik age, were found only in wells at Zolny Ovrag and Yablonovy Ovrag. No Domanik specimens were obtained from the Saratov section of the Volga valley (specifically from Teplovka), but Kondratyeva's short description of those rocks as black limestone which give off an odor of burnt rubber when in contact with fire warrants the assumption that the lithology of the Domanik in this section is also typical.

In a previous paper [38] on Domanik sediments in the southern Urals, it was pointed out that "the extensive Domanik of the southern Urals are cratonic deposits even though they are found in a geosynclinal region; this is explained by the fact that this region behaved as a cratonic area during Domanik time, and for a long time afterwards... It follows, therefore, that these sediments may not be confined by the western flank of the Urals and that they may occur on the eastern side of the Russian platform." The discovery of Domanik sediments in many drill holes east of the Urals confirmed this hypothesis fully.

Correlation of Domanik sediments from the Volga-Urals province with those of the southern Urals is possible. The (cratonic) deposits consist of gray limestones, black limestones, marls, and clays. The gray limestones, as in the Urals, are dense, clearly recrystallized, and contain abundant pteropod and some brachiopod remains. Microscopic examination reveals the texture of the recrystallized matrix may be coarse to fine. Many transverse sections of Tentaculites, surrounded by calcite flakes which seem to form "roses", occur in both Domanik sections studied. Considerable silicification of cement and organic remains is observed in some cases. Films of organic matter are not abundant; they may occur between calcite grains.

The black limestones are outwardly uniform, fine grained, and uniformly recrystallized. They have a weak luster and no, or very weak, layering which is controlled by white streaks on a black background. These rocks consists of microscopic, irregularly outlined calcite grains between 0.01 and 0.6 m in diameter. The spaces between the grains are occupied by sapropel-clay which acts as a cement. Pteropods, filled with crystalline calcite, are abundant; other forms are virtually absent. Dolomite rhombohedra occur less frequently in the dark matrix. This combination of textural characteristics also describes the black limestones of Domanik age in the southern Urals.

In hand specimen, the marls have the appearance of a dense, dull-black, somewhat coaly rock with poorly expressed layering, due primarily to the random orientation of the pteropods. Microscopically, the marls consist of a dark-brown or dark-red matrix composed of pelitic material, organic matter, and a fine carbonate powder. The texture of this sapropel-pelite carbonate mixture is not homogeneous, but contains aggregates which are dark in their centers and light on their peripheries. Elongated calcite fragments with dimensions between 0.025 by 0.015 and 0.6 by 0.075 mm occur among these aggregates; calcite also occurs as large individual grains and amorphous aggregates. Dolomite rhombohedra 0.015 by 0.05 mm can also be observed. Pteropods Tentaculites and Styliola occur either as isolated individuals or in groups strongly cemented by calcite. Threadlike shells of young brachiopods and small fragments of Tentaculites are also encountered. Organic matter occurs as bright-red spots and streaks, or may be mixed with pelitic material.

The argillaceous rocks of Domanik age are distinguished from the marls by their low carbonate content and especially by their paucity of pteropod remains.

Table 15 presents the results of the chemical analysis of Domanik sediments. It shows the large amount of organic material in the Domanik, and concentrations of iron and manganese which are lower than for Pashysky and sub-Domanik lithologic analogues. Table 16 shows the mineral relationships in Domanik carbonates. This table indicates that the degree of dolomitization in the Domanik is the same as, or is slightly lower than, that in the sub-Domanik. Therefore, the sharp increase in the quantity of organic matter in the Domanik had no effect on the deposition of dolomite.

A comparison of the chemistry of the Domanik sediments in the Trans-Volga region with the Domanik in the southern Urals is presented in table 16a. The stratigraphically and petrographically similar Domanik sediments of the two areas also exhibit chemical similarities. They contain nearly equal amounts of carbonates and organic carbon, and are to about the same degree dolomitized. None of the rocks in the Trans-Volga region are as rich in organic matter as are the bituminous shales of the Tashkyskan district in the southern Urals. But, as the sampling of the Trans-Volga region is incomplete, it cannot be said that the amount of organic matter in the cratonic areas of the Trans-Volga

TABLE 15. Average concentration of selected elements in sub-Domanik sediments (%)

Rock	Total Carbonates computed from CO_2	Organic C	Fe	Mn	P	Remarks
Clay	13.4	6.09	None	None	None	None
Marl	55.6	3.14	1.28	0.09	0.021	6 samples
Argillaceous limestone	80.4	1.70	0.79	0.012	0.06	3 samples
Limestones enriched with organic matter	92.05	1.31	0.37	0.20	None	3 samples
Normal	96.97	0.29	None	None	None	None

TABLE 16. Comparison of Domanik sediments of the Trans-Volga and the Southern Urals (%)

Rock and Well Number	Total Carbonates	Dolomite	Calcite	Degree of Dolomitization	Excess MgO	Excess CO_2
Marl						
Baltayevo No. 2, sample 2010	59.85	14.50	45.35	24.2	None	0.34
Sernovodsk No. 3, sample 1920	60.53	4.90	55.63	8.1	0.63	None
Sernovodsk No. 3, sample 1946	42.57	1.09	41.48	2.5	0.51	None
Sernovodsk No. 3, sample 1963	48.31	9.77	38.54	20.2	0.70	None
Argillaceous limestone						
Sernovodsk No. 3, sample 2013	72.51	3.37	69.14	4.6	0.63	None
Sernovodsk No. 3, sample 1918	85.39	1.64	83.75	1.9	0.72	None
Sernovodsk No. 3, sample 1926	78.16	6.36	71.80	8.1	None	None
Sernovodsk No. 3, sample 1968	89.90	3.85	86.05	4.3	0.01	None
Sernovodsk No. 3, sample 1981	90.42	2.69	87.73	2.9	0.32	None

TABLE 16A. Comparison of Domanik sediments of the Trans-Volga and the Southern Urals (%)

Rock	Total Carbonates	Dolomitization	Organic C	Remarks
Bituminous shale				
Southern Urals	<1	None	24-35	
Trans-Volga	None	None	None	Not represented in collection
Clay enriched with organic matter				
Southern Urals	2-3	Minor	5-14	
Trans-Volga	13.4	?	6.09	
Marl				
Southern Urals	48.59	About 12	2.12	Along Asha river; C over 22% (actually bituminous shale)
Trans-Volga	55.6	13.8	3.14	
Dark argillaceous limestone				
Southern Urals	84.70	5	2.15	Along Sim river; C over 10%
Trans-Volga	80.4	4.3	1.70	
Gray limestone				
Southern Urals	92.05	About 2.5	0.34	
Trans-Volga	96.97	?	0.29	

is less than in the geosynclinal areas of the Urals. More important is the fact that the degree of silicification is higher in the southern Urals. This silicification appears in the form of concretions and as irregular silica zones in marls and limestones. Although some silicification has been observed in the Trans-Volga region, no large amounts have been. It is possible that the degree of silicification represents a real difference between Domanik sediments

in the two areas.

The Domanik sediments occur in a north-trending belt in the eastern portion of the Russian platform. This zone extends from the western flank of the Urals west to Saratov. The north-south length has not been definitely established, but it is thought to be on the order of 1,200 km. It includes the Timan and probably part of the Pechora basin on the north and extends into the cis-Caspian basin on the south. The width of the zone is not less than 700 km through the Ufimskoye plateau.

Apparently, local enrichments of organic matter occurred episodically and sporadically in the west. The Domanik sediments are characterized by sustained deposition and burial of such enormous quantities of organic matter that it was the most colossal accumulation of organic matter in the history of marine sedimentation on the Russian platform, and one of the greatest in the world. The Domanik sediments, however, were deposited over a very small portion (possibly less than one-sixth) of the area occupied by the early Frasnian sea.

The faunal assemblage is a fundamental element in the determination of facies. The Domanik does not include all representatives of the contemporary marine population. Coral and algae are absent (these forms contribute to the accumulation of limestone). Crinoids and bryozoans are rarely encountered and only in the gray limestone. Water depth and the character of the bottom sediments account for these biofacies characteristics. Paleozoic algae and corals, like Recent algae and corals, were near-shore organisms that required shallow water and a hard bottom. The crinoids and bryozoans could have thrived in considerably deeper water, but they, too, required a hard bottom. If it is assumed that all sediments deposited during Domanik time accumulated in deep water, perhaps on the outer portion of the continental shelf, then benthonic forms played a subordinate role in the environment. The dominance by planktonic forms, pteropods, and some goniatites, is typical of the deeper portions of Recent seas. The small size of certain benthonic forms (Lingula, Buchiola, and Ontaria) and the fact that these occur as isolated individuals are also typical of deep-water environment. The very fine texture of the pelitic material in Domanik marls and argillaceous limestones indicates that these were deposited below the zone of turbidity. The Domanik sea seems to have had a normal dissolved gas regimen, a good oxygen supply, and, apparently a good vertical circulation, in spite of its 100-to 300-m depth.

The source of organic matter in the Domanik was not the too-deep benthos. It could not have been carried from the land because of the great distance from the shore to place of deposition. Also, the Domanik contains no fossil flora. The upper layers of plankton provided the organic material. The density of the plankton population in the eastern portions of the Domanik sea seems to have been 5 to 10 times greater than "normal" density. Abundant pteropod remains also indicate a well-developed planktonic population, for pteropods are heterotrophic and require much phytoplankton for sustenance.

The development of an abundant phytoplanktonic population requires an abundant supply of nutrient salts. These must be carried from the shore or from the bottom sediments by relatively strong horizontal or vertical circulating currents. The transportation of nutrient salts by horizontal currents is excluded because the extent of the Domanik sea was too great and the distribution of source areas was inadequate. A radical change in the hydrological conditions in the eastern portion of the sea during the transition from the sub-Domanik to the Domanik, resulting in the formation of strong vertical circulation, supplied nitrogen and phosphorus compounds to the pteropods and the plankton. Hydrological conditions again changed and the supply of nutrient salts to the upper layers of water was cut off. The plankton of the Domanik sea ceased to flourish.

The Overall Distribution of Organic Matter in the Frasnian Sediments of the Volga-Urals Province

Table 17 compares the distribution of organic carbon in the lower Frasnian sediments. The great quantity of organic carbon in the Domanik sequence makes the much smaller amount in the Pashysky and sub-Domanik sequences appear unusual. Clarke[49] computed the average amount of organic carbon in sedimentary rocks and found that the concentration in sandstone is 0.05 percent, in limestone 0.104 percent, and in shale 0.94 percent. At a later date, Trask obtained an average organic-carbon concentration of 1.08 percent for all sedimentary rocks on the basis of a much larger body of data (over 10,000 analyses) than that used by Clarke. The Pashysky and sub-Domanik concentrations are nearly equal to the average value for sandstone and siltstone, except for a few local higher concentrations.

The clays, marls, and limestones of the Domanik sequence contain at least 3 times as much organic matter as the Pashysky and sub-Domanik sediments; information on the sandstone-siltstone shoreline facies is lacking. The difference is even greater when the absolute mass of organic matter in a column of rock with a cross-section area of 1 m^2 and height equal to the thickness of the Domanik is compared with similar columns for the Pashysky and sub-Domanik. Cores were not complete for all points in the cross section. Therefore, the comparison in

TABLE 17. Distribution of organic carbon in lower Frasnian sediments (%*, number of samples in parentheses)

Rock	Pashysky (508)		Sub-Domanik (155)		Domanik (90)	
Sandstone	0.18		0.17		-	
Siltstone	0.40		0.54		-	
Clay	0.63	Average 0.75	0.61	Average 0.74	6.09	Average 2.14
Marl	1.95		1.07		3.14	
Argillaceous limestone	0.69		0.50		1.70	
Normal limestone	0.18		0.22		0.29	

* These values are averages of data given in the preceding tables.

TABLE 18. Distribution of absolute amounts of organic carbon in lower Frasnian sediments; carbon concentrations; in metric tons per square meter, average over entire area

Sequence	Borovka Nos. 2 and 3	Tukmakly No. 2	Krym-Saray No. 3	Tuymazy No. 138	Baltayevo No. 2	Kargaly No. 1	Total, All Wells
Fine-grained Domanik sediments	10.57	5.88	2.46	1.85	1.62	1.40	23.78
Sub-Domanik	2.31	1.74	0.52	0.48	0.52	0.30	5.87
Pashysky	1.45	1.15	0.96	0.69	0.92	0.67	5.84
Ratio between values for Domanik and sub-Domanik; absolute amounts in Pashysky sediments assigned unit magnitude	7.2:1.6:1	5.1:1.5:1	2.6:0.5:1	2.6:0.7:1	1.8:0.6:1	2:0.5:1	4:1:1

table 18 is taken from the Borovka-Tukmakly, Krym-Saray, Tuymazy, Baltayevo, and Kargaly drill holes. The numerical ratios between rocks of Pashysky and sub-Domanik age was taken from table 1; the specific gravity of the rocks is assumed to be 2.6.

The difference between the absolute amount of organic carbon in the Domanik and the Pashysky sequence on the eastern portion of the area, where the Frasnian is much thinner, is considerably less than in the western portion (Borovka-Sernovdsk-Tukmakly), where the ratios vary between 5:1 and 7.3:1. The Pashysky includes large clay and marl components in the eastern sections and these contain most of the organic matter in the lower Frasnian sediments.

The organic materials in the Domanik and the Pashysky differ in origin as well as in mass. Horizontal currents transported substantial amounts of vegetation from a land source to areas of Pashysky accumulation. These horizontally transported organic remains exceed the planktonic in the clays, marls, and limestones. During Domanik time, however, planktonic forms were dominant.

(Part 2 of 3 will appear in the June issue of IGR)

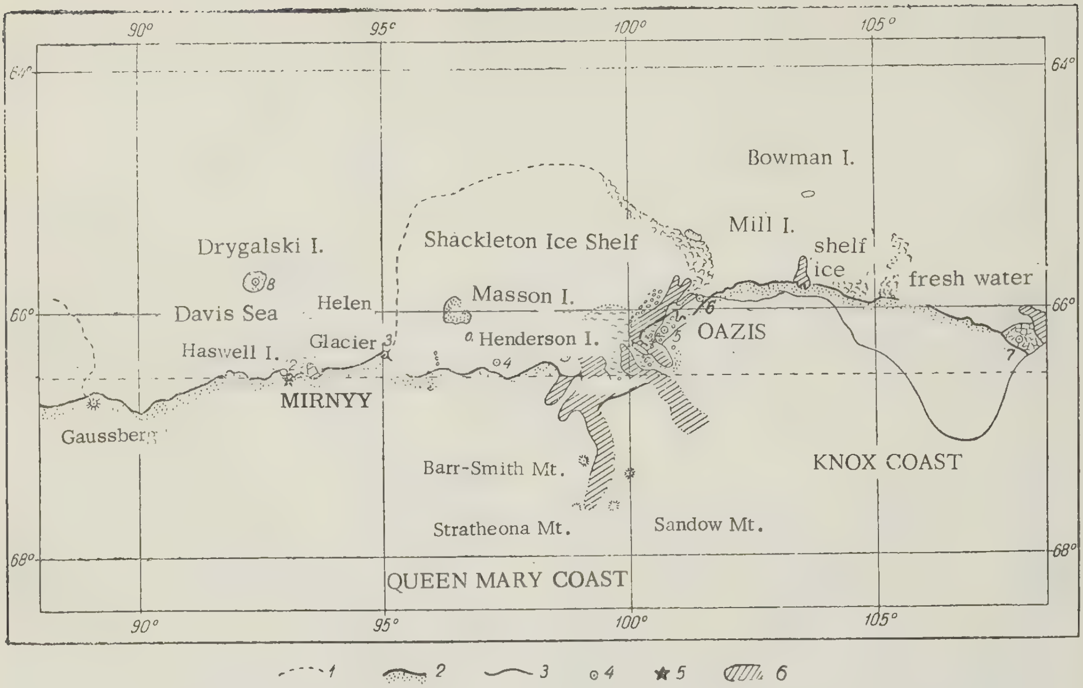

FIGURE 2. Schematic map of the section of Antarctic coastline explored by the first Antarctic expedition of the Academy of Sciences, U.S.S.R., in 1956.
(1) approximate boundaries of ledge glaciers; (2) continent boundary; (3) continent boundary as indicated on the existing maps and differing to a considerable degree from our boundary; (4) astronomical points determined by the expedition of the Academy of Sciences, U.S.S.R.; (5) Mirnyy; (6) most prominent glaciers.

a complete geologic picture of the region and exact names of rocks collected cannot be given. Therefore, this paper is a preliminary outline of the first general impressions made immediately after the expedition returned to the Soviet Union.

Except for well-exposed bedrock in Banger Oasis, few bedrock outcrops were found along the explored coast; areas (Barr-Smith Mountain and others) rising above the plateau along the edge of the Denman and Scott glaciers were not visited. In many instances, bedrock outcropped from beneath snow and ice along the continental shore cliffs that extended along the Shackleton Ice Shelf. Such outcrops were frequently recovered by snow and later re-exposed. New outcrops seemed to have appeared after avalanches.

The outcrops in the shore cliffs remained inaccessible at this time because the flight route over the Shackleton Ice Shelf and the intermediate landing base were at a considerable distance from the shore. A series of small outcrops comprise nunataks in the ice of the Shackleton Ice Shelf in the ice ledge fringing the coast. In several places, small islands were not far from shore.

Antarctica consists of two basic formational units: the ancient shield in the east and the young (Mesozoic or Alpine) fold region in the west.

The territory explored is located within the confines of the shield in which, with few exceptions, ancient crystalline rock predominates. At Mirnyy, granitoids, primarily charnockites and migmatites, occur. According to data provided by the Mawson expedition, granites and gneisses also form all the nunataks of the Shackleton Ice Shelf and the outcrops of the adjacent continental shore cliffs.

Banger Oasis is underlain by gneisses intruded by ancient granites. The granites are pink and gray; grain size of the pink granite is irregular. Pegmatites were frequently observed. The gneisses contain biotite, hornblende, and garnet. Their strike is uniform, attitude vertical or dipping steeply to the southwest. A few small, sharp (gothic) folds with vertical axial planes were noticeable. These are generally compressed, sharp, straight isoclinal folds, vertical or slightly tipped to the east.

Dikes of basic rock cut the crystalline nucleus. One vertical gabbric-diabase dike, about 150 meters long, extends in a straight line across Banger Oasis; its black color contrasting with the general brown-gray countryrock. Other

dikes, usually not very long, are composed of gabbric diabase. These basic dikes may be contemporaries of the dolerites which form sill intrusions in the Beacon sandstone of Victoria Land and in the Queen Maud Range. Several small islands and nunataks (apparently also formed by crystalline rocks) were observed from the air near the shore east of Banger Oasis.

Snyder rocks, four nunataks of similar character, stand above the ice near the shore at the most eastern point where a successful landing had been made (107^{o} 41' E.; the astronomic point was determined by I. P. Kucherov and V. I. Zakopaylo). They are gray granites containing feldspar grains up to 4 centimeters in diameter and xenoliths of variable composition as much as 1.5 meters in diameter. The shapes of the nunataks are very closely related to the granite cleavage.

Gaussberg is a young volcanic cone composed of leucite basalt. Near the summit, which is about 371 meters above sea level, native sulfur occurs. The birth of this cone probably dates to the Neogene, more specifically to the beginning of the Quaternary.

Obvious traces of ancient and more intensive glaciation were observed in all areas of basic outcrops. Morainal material is present in these areas to a greater or lesser extent. Erratic boulders were found even on the slopes and at the very summit of Gaussberg. In Banger Oasis, depressions between volcanos are filled with morainal material. Erratic boulders have also been found at the top of all volcanos. Furthermore, surfaces smoothed and polished by glaciers and glacial hatchings could be frequently observed on basic outcrops. Small, recent moraines were found in two places in the vicinity of Mirnyy and on the shore at Farr Bay. A thick morainal belt was observed directly west of the Oazis [U. S. S. R.-IGY station]. It is caused by the glacier which is skirting the Oazis. The morainal material consists of granites, gneisses, and crystalline schists in the western part of the region from Gaussberg to Farr Bay. A few erratic boulders of multicolored (yellow, gray, pink, light-violet, and brownish-red) quartzite, sandstone, and gravel were found in the recent moraine framing the Oazis and in the oasis itself with the crystalline rock fragments including dolerite. At the most eastern point, the sandstone content of the morainal material increases. These boulders were apparently formed from sandstone developed under the cover of ice somewhere inland to the south and correspond to the Beacon series.

Crystalline rock of the ancient, apparently Precambrian, shield nucleus predominates in the area investigated. Younger sedimentary formations are totally absent. Only traces of sandstone, corresponding to the Beacon series, were found as morainal boulders in the eastern part of the region.

Basic dikes, that could be compared to the lower Mesozoic dolerites cutting the Beacon series, occur in Banger Oasis. Recent lavas were noted in the Gaussberg cone. The nucleus of the eastern Antarctic shield is composed of gneisses, schists, and granites, principally charnockite. A new variety of charnockite, enderbite, was described from eastern Antarctica (Enderby Land). It is possible that the strongly fractured schists found at Cape Adare, on the shore of Ross Sea belong to the Reef system.

Erratic boulders of unmetamorphosed Cambrian dolomites containing archeocyathids and algae were found in the Beardmore Glacier moraine which decends to the Ross Sea, and in a boulder of archeocyathic limestone dredged from the Weddell Sea. The Beacon sandstones are apparently widespread and include coal seams. The time of their deposition probably extends from the Devonian (judging by fossil fish) to Permian. Glossopteric, Gondwanic flora were found in this formation. The Beacon sandstones are prevalent in Victoria Land, Queen Maud Range, and George V Coast.

Erratic sandstone boulders of Beacon-type sandstone were found in morainal material on Knox Coast and in Banger Oasis. This indicates a spread of the Beacon series inland to the south.

Similar dipping sandstones and graywackes were noted on Princess Martha Coast in the Atlantic sector of Antarctica. It may therefore be assumed that, originally, the Beacon series had an extremely wide distribution over all or over the greater part of the area of the Antarctic shield. These are the youngest sedimentary rocks as yet found on the shield.

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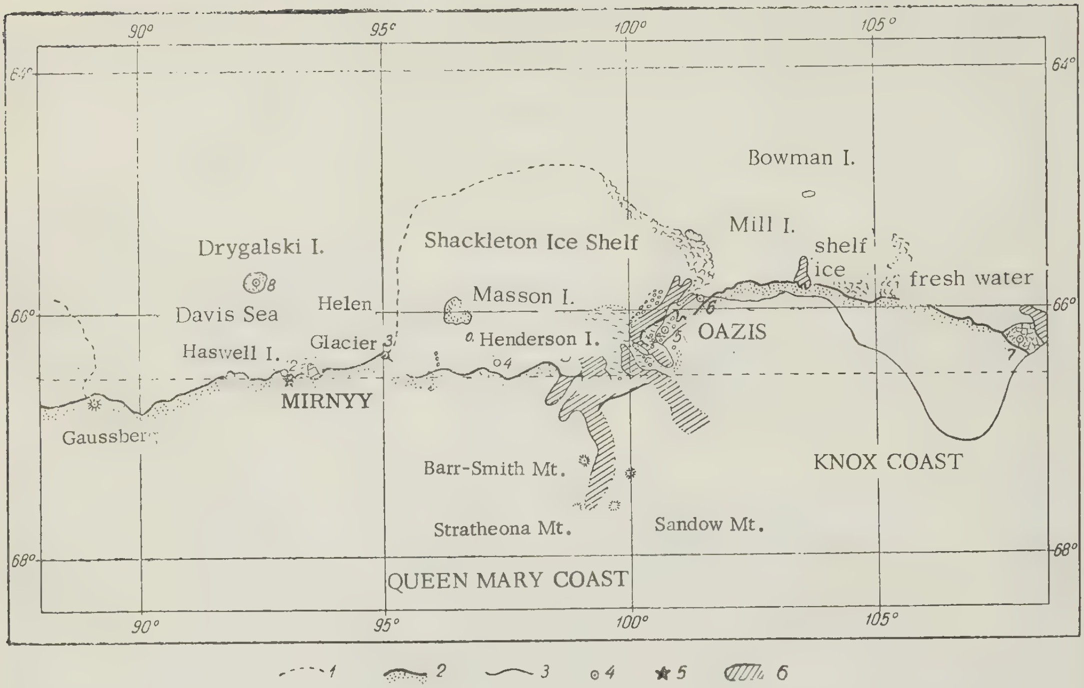

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fines of the Antarctic shield.

The boundary of the fold region of western Antartica is indistinct; Victoria Land should not be included in this region, despite the tendency to do so in the available literature. Although Terror and Erebus volcanos are located in Ross Sea, the Paleozoic Beacon sandstones in Victoria Land, are horizontal. It would appear that even Marie Byrd Land, or at least its western part, should not be considered a part of the young fold region. The boundaries of the ancient shield should be drawn to the east of Victoria Land and Queen Maud Range in the region of the Ross Sea, and to the west of the Moltke Nunatak in the region of the Weddell Sea.

I, in opposition to other authors, consider that the Paleozoic and Mesozoic fold zones pass through western Antartica. A narrow belt of the Tertiary alpine-type folding is possible, though no deformed Tertiary deposits have yet been found.

Large, fairly recent, fractures determine, in part, the morphological character of the continent and bottoms of adjoining oceans. Submerged ranges, such as the Kerguelen-Gauss Ridge, framing Antarctica, or abutting the continent, are not young fold features developing on a geosynclinal foundation. They are young, possibly even Quaternary vertical uplifts which may intersect any of the older structural features in different directions. The same applies to the central Antarctic range and to the Lomonosov Range in the Arctic basin (Arctic Ocean).

Paleoclimatic factors, coal in the upper Paleozoic strata of the Beacon series, the Jurassic and Tertiary character of the flora, and so forth, indicate a shift in poles during the history of the earth.

A further study of the Beacon sandstones would contribute a great deal to the solution of the Gondwanian problem. If Gondwana were one large continent including Antarctica, its split fractions did not drift in different directions, but some sank and are now below sea level. The type of formation represented by the Karroo system in South Africa would be an important factor in solving this problem. If it is a molasse filling a frontal downwarp, and this seems to be the case, there should be a submerged folded mountain system to the south. If so, a geosynclinal region dividing the African and Antarctic shields existed during Hercynian time. Later, this geosyncline became a mountainous region and clastic material was carried down both sides. This material eventually formed the Karroo system and the Beacon sandstones. It is possible that this range is analogous to the Urals which, on one hand, separated the European and Siberian shields and, on the other, unified Eurasia.

Each nunatak is a miniature oasis. Because of the intense absorption of solar heat, an increased thaw around the nunatak in summer results in the formation of small lakes. The same applies to all the large lake regions called oases. The inner heat of the earth plays no part in their formation.

ASSOCIATION OF ORE BOD ES IN GRANITOIDS OF THE CAUCASUS AND THE GENESIS OF THESE ROCKS[1]

by

G. M. Zaridze[2]

• translated by L. Drashevska •

ABSTRACT

The Caucasus lie within the Alpine orogenic belt. Their geotectonic structure is very complex. It can be subdivided on the basis of various geotectonic characteristics, facies changes, and variable degrees and types of magmatic activity. Effusive magmatic activity in the different periods of geologic history occurred before folding; this is especially evident in geosynclinal zones. Granitoids of different ages are synchronized with the accumulation of sediments under regressive sea conditions. In some cases, the age of the granitoids have been absolutely determined. Metasomatic granitization probably occurred in the early structural stages; granitic magma intrusions in the later stages. Ore-bearing solutions are associated with both types of granite emplacement. The author, however, assumes that ore deposition resulted from the penetration of ore-bearing solutions directly from depth with no relation to the formation of the granitoids.

* * *

It is known that the Caucasus mountains are a part of the Alpine orogenic system. Their geotectonic structure is very complicated, but it can be subdivided into several structural elements among which proper geosynclinal sections and rigid blocks may be distinguished. Distinctions between these elements involve not only different geotectonic regimens and consequently differences in facies of sediments, but also differences in magmatic activity.

Of special interest to geologists is the peculiar relation of magmatic activity to the tectonic regimen in areas of its development. Petrographs seldom elucidate the relation of different magmatic processes to the character of movements of the earth's crust. In many cases, it is not clear which igneous rocks formed during the pre-tectonic time and which were associated with the tectonic phase; there is no understanding of the peculiarities of the evolution of magma when it is formed in geosynclinal and block areas; and it is not known how to determine which small intrusions are the roots (feeder channels) of effusives.

In the Caucasus, Georgia is one of the territories most thoroughly studied petrographically. The two geosynclinal regions are the southern part of the Great Caucasus fold system and the Adzharo-Trialetsk fold system. These systems developed differently, and, therefore, have different histories of magmatic activity. In the flat-folded regions of the Georgian and the Somkhetsk blocks igneous activity had its peculiar features.

To illustrate the character of igneous activity in different geotectonic regions, a scheme of the distribution of igneous rocks in Georgia was compiled (table 1). In this scheme, the fold system of the southern slope of the main range together with the Georgian block (the southern part of the Great Caucasus) and the Adzharo-Trialetsk fold system together with the Somkhetsk block (the northern part of the Little Caucasus) are considered separately.

This scheme presents in chronological order all known magmatic formations. Volcanic sedimentary and effusive rocks are subdivided into two groups: 1) magmatic rocks associated with the geosynclinal stage of development of certain areas and 2) magmatic rocks which were formed during the stabilization of blocks. Two principal groups of intrusive rocks are distinguished: those formed during the accumulation of sediments and the volcanic activity and those associated with folding. It is know that various types of ores are associated with these igneous rocks.

IGNEOUS EXTRUSIONS IN GEOSYNCLINES

At early stages of their development, geosynclines, as a rule, are characterized by the accumulation of specific deposits of the volcanic sedimentary type. These characteristic complexes are known in the lower Paleozoic geosynclines of the Caucasus, in the Dzirul and Loksky massifs, as well as in the northern Caucasus, where they are represented by the Chogom, Khasaut, Amanchat, and other formations. Analogous complexes also occur in the upper Paleozoic and in many Jurassic and Tertiary geosynclines of the Caucasus and the Transcaucasus. Similar examples are found elsewhere in the U. S. S. R. and abroad, such as the Bohemian massif and Carpathian mountains.

The geosynclines in which volcanic activities

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[1]Translated from Proiskhozhdeniye granitoidov i ikh rudonosnost na Primere Kavkaza: Sovetskaya Geologiya, 1958, no. 4.

[2]Georgian Polytechnical Institute.

TABLE 1. Scheme of distribution of igneous rocks in Georgia, U.S.S.R.

	VOLCANIC-SEDIMENTARY AND EFFUSIVE ROCKS		INTRUSIVE ROCKS		Character of ores
	Geosynclinal facies	Facies of resistant blocks	Pre-orogenic magmatic phase	Syn-orogenic magmatic phase	
	I. Fold system of the southern slope and the Georgian Block (southern part of the Great Caucasus)				
1	Amphibolite; hornblende, hornblende-biotite, biotite, and other schists of the main Caucasian range and Dzirul massif. Precambrian (?) - lower Paleozoic.		Gabbro, amphibolite, and others.	Some granitoids of the Dzirul massif (Caledonian).	
2	Slate and schist (micaceous chlorite, and other schists; quartzite; and marble) of the main Caucasian range (Abkhasia) and of the Dzirul massif. Lower Paleozoic and possibly younger.		Serpentine and other ultrabasics*. Gabbro, diabase, and veins.	Granitoids of the main Caucasian range and of the Dzirul massif. Upper Paleozoic (Hercynian).	Chromium-nickel ores.
3	Desi formation (phyllite, sandstone, marble, metamorphosed volcanics). Upper Paleozoic - Lower Cretaceous.		Ultrabasic rocks (pyroxenite and others). Gabbro, diabase, and veins*.	Granitoid, syenite-diorite, quartz-diorite. Upper Paleozoic-lower Mesozoic.	Rare metals and gold.
4		Volcanic quartz-porphyric and quartz-albitophyric formation, in places containing basic effusives and their tuffs; distributed at margins of the Dzirul massif (lower tuffites). Upper Paleozoic.		Quartz prophyry, quartz albitophyre, and diabase-porphyrite (effusives and veins).	
5	Schist and sandstone of the southern slope of the Great Caucasus; in places containing effusives and their tuffs. Lower-Middle Jurassic. Middle Jurassic volcanogenic-sedimentary spilitic-diabasic-porphyritic formation.		Gabbro-diabase-porphyrite rocks (effusives and veins).	Granitoids, quartz-diorite and monzonite, dacites and albitophyre. Jurassic.	Rare metals, gold, copper-pyrrhotite, polymetallic ores, barite.

6		Volcanics. Upper Jurassic.	Olivine basalt, olivine trachy-basalt, andesite basalt, trachyte and essexite. (effusives and veins).		
7		Tuff, siliceous clay, sand-stone, and siliceous lime-stone. Upper Cretaceous (Ceno-manian-Senonian).	Teschenites of the Iori river gorge (veins).		
8		Stratified limestone, tuff-aceous sandstone, zeolite-bearing basalt, trachy-basalt and its tuffs. Upper Cretaceous (Turonian-Coniacian).	Alkali basalt, trachybasalt, teschenite and phonolite (effusives and veins).		
9	Cenozoic and more ancient deposits.		Effusive basalt, andesite basalt, analcitic basalt and their vein facies (teschenite). Upper Pliocene.	Dacite and albitophyre. Upper Pliocene.	Rare metals, polymetallic ores, gold.
10			Dacite, andesite dacite, andesite basalt, and basalt. (effusives). Quaternary.		
	II. Adzharo-Trialetsk System and the Somkhetsk Block (Northern part of the Little Caucasus)				
1	Amphibolite; hornblende, hornblende-biotite, biotite and other schists of the Khrami and Loksky mas-sifs. Precambrian (?)- lower Paleozoic.		Gabbro-amphibolite.	Some granitoids of the Khrami massif. Lower Paleozoic (Caledonian).	
2	Slate and schist (mica, chlorite, and other schists; quartzites, and marbles) of the Loksky massif. Lower Paleozoic.		Gabbro, diabase and others (veins).	Granitoids of the Loksky massif and some granitoids of the Khrami massif. Upper Paleozoic (Hercynian).	Gold, poly-metallic ores.
3		Volcanic quartz-porphyrite and quartz-albitophyre, also sandstone and clay with coaly plant remains (lower tuffites). Upper Paleozoic.	Quartz porphyrite, quartz-porphyry, and quartz albito-phyre (effusives and veins) of the Khrami massif area.		

	VOLCANIC-SEDIMENTARY AND EFFUSIVE ROCKS		INTRUSIVE ROCKS		Character of ores
	Geosynclinal facies	Facies of resistant blocks	Pre-orogenic magmatic phase	Syn-orogenic magmatic phase	
	II. Adzharo-Trialetsk System and the Somkhetsk Block (Northern part of the Little Caucasus) (continued)				
4		Shale, sandstone, and conglomerate and albitic porphyrite (lower section changing into andesite hornblende and andesite-pyroxene porphyrite and their pyroclastic deposits. Middle Jurassic (Lias).	Diabase-porphyritic rocks (effusives and veins) of the Loksky massif area.	Granitoids (Poladaur). Jurassic.	Polymetallic ores and barite.
5		Transgressive volcanic-calcareous rocks and volcanics. Cenonanian-Coniacian.	Quartz porphyry and albitophyre (effusives and veins) of the Loksky and Khrami massifs.		Iron ore, polymetallic ores, pyrite, barite, gold.
6	Volcanic sediments consisting of interstratified terrigenous material, marl and clayey marl, spilite (in lower section); augite-andesite and hornblende-andesite porphyrite and their tuffs. Upper Aptian, Albian, Cenomanian, and lower Turonian.		Albite, augite-andesite and hornblende-andesite porphyrite, and spilite (effusives and veins).		
7	Flysch, andesite, and andesite-dacite lava, and pyroclastics of the gorge of the Algeti river. Lower part of lower Eocene		Andesite and andesite-dacite (effusives and veins).		
8	Volcanic sediments consisting of porphyritic flows, their pyroclastic rocks and terrigenous material. Middle Eocene.		Gabbro-diabase-porphyrite rocks (effusives and veins)	Granitoids, syenite-diorite,* quartz monzonite. Upper part of middle Eocene to lower part of upper Eocene.	Copper ores, polymetallic ores, gold.

9		Marl-clayey volcanics (trachytic) of the Supsa river gorge. Upper Eocene (?).	Trachyte (effusives veins).	Analcite syenite of the Supsa river gorge*. Upper Eocene.	Gold.
10	Sandstone, tuffaceous sandstone, shale, limestone, andesite-basalt flows and their pyroclastic rocks. Upper Eocene.		Andesite basalt (effusives and veins).		
11		Volcanic sedimentary rocks (upper Goderzdzi formation), andesite basalt and pyroclastics of the Akhaltsikh basin. Miocene-Pliocene.	Andesite basalt (effusives and veins).		
12		Dislocated Tsalk lava composed of andesite basalt and intercalated lacustrine deposits in Tsalk area and Akhalkalak Highland. Upper Pliocene.	Andesite basalt (effusives).		
13		Andesite basalt, andesite, more acid lava in the Adzharo-Trialetsk range and on the Akhalkalak Highland. Pleistocene.	Andesite basalt, andesite, andesite dacite, and others (effusives).		

* Denotes ore host.

developed were associated with the prevailing downwarping of the earth's surface and the accumulation of sediments. Most of the basic magma was ejected. The volcanics of geosynclines, including pyroclastic deposits, belong to the pre-orogenic rocks and are contemporaries of terrigenous sediments as a whole. At the same time, magmatic bodies were emplaced; these are composed of diabase, gabbro, and other rocks, either stocks, or otherwise irregularly shaped plutons. Also, concordant injections along planes of stratification, such as sills, and discordant ones, like dikes, were formed at that time. Apparently all these intrusions represent roots of effusives, or they are massifs which did not penetrate the surface and cooled at depth. In a few places, intrusives directly grade into effusives and were concurrently deformed. However, all the granitoid intrusions observed in the described region crosscut the effusives and massifs.

The Adzharo-Trialetsk geosyncline might be mentioned as an example. During the initial phases of this geosyncline's development in the Eocene, the volcanic sediments of porphyrite composition were accumulated. At the end of the middle Eocene, volcanic activity decreased and later ceased completely, uplift was the dominant geosynclinal activity, shallower basins were filled with argillaceous sediments containing plant remains and, in places, gypsum. These developments were due to processes associated with the so-called Trialet tectonic phase which also resulted in the emplacement of syenite-diorite intrusions within the geosyncline.

The possibility that the effusives and intrusives were contemporaneous resulted in a rather simple solution to the long disputed question of the age of teschenites found in western Georgia and the Iori river gorge. Formerly, their emplacement was thought to have occurred in the Attich tectonic phase between the Miocene and Pliocene. Some geologists erroneously correlated teschenites of the Kutaisi area with veins of teschenites near Chkvishi, Patara-Oni, and Kveda-Shavra, situated in Verkhnyaya Racha. However, the Patara-Oni teschenite cuts Oligocene rocks, but the other two exposures cut the Karagan [Tr.: Miocene] deposits. These teschenites, known to be Tertiary in age, are thought to be the roots of the effusive Namanev zeolite-bearing basalt. The lower Sarmatian deposits are the youngest among rocks overlain by the Namanev effusives. These effusives, as well as teschenite veins, can be tentatively assigned to the upper Pliocene.

Teschenites of the Kutaisi and Sinatle areas are roots of Turonian basic, alkali-rich effusives. Teschenite from the Iori river gorge, described by A. P. Gerasimov [5], is of the same age.

Volcanic sediments comprising the Mtavari formation of Turonian age are zeolite-bearing titanium-augite-olivine basalts containing, in places, potassium feldspar; trachybasalts; and occasionally, phonolites and their tuffs.

The age of the teschenite of the Kutaisi area was determined by the argon method to be 41 million years [18] stratigraphically, the teschenite occurs in the interval between the end of the Upper Cretaceous and the middle Eocene. Therefore, teschenites of the Kutaisi and Sinatle areas should not be correlated with teschenites of Chkvishi, Patara-Oni, and Kveda-Shavra. It should be noted however, that the age of teschenites of the Kutaisi area, as determined by the argon method, does not correspond completely to their age as determined on the basis of stratigraphic investigations.

In September 1956, the author observed in the Bohemian massif teschenite outcrops near Teschin. The well-known Czechoslovakian geologist, Dr. V. I. Zoubek, informed the author that, at present, teschenites of Teschin are considered to belong to the effusive facies.

In the Caucasus, in areas of acid volcanic sediments and of cross cutting hypabyssal bodies of quartz-porphyrite and quartz-albitophyre composition, no granitoid intrusions have been found to be contemporaries of the crosscutting bodies. Examples are the upper Paleozoic volcanic formations of the Dzirul and the Khrami massifs and the Lias volcanic formation of the Klukhorsk massif. Therefore, it was concluded [13] that in geosynclinal areas the effusive and intrusive magmatic activities were separated in time from intrusions associated with the tectonic phase; thus, the hypothesis that acid effusives were connected with large bodies of syn-orogenic granitoid massifs through the feeding channels is incorrect.

THE TIME OF GRANITOID MASSIF FORMATION IN THE DEVELOPMENT OF GEOSYNCLINAL CYCLES

The formation of granitoid massifs took place in connection with tectonic phases which deformed geosynclinal sediments. The effusive activity of acid and basic magma ceased at that time. It is known that the beginning of folding is marked by the formation of early orogenic regressive rock masses. It would seem that acid effusives would occur in this mass by means of feeding channels, connected with granite batholiths. However, these were not observed in the investigated area.

In western Georgia, the formation of granitoid intrusions is associated with the accumulation of Bathonian coal-bearing rocks. The rocks, which replaced the Bajocian geosynclinal volcanic-sediments, do not contain positive evi-

dence of considerable volcanic activity. At the margin of the Dzirul massif, there are outcrops of Bajocian porphyrite. Dislocated rocks of this formation are cut by a large granitoid intrusion (Khevisdzhvar) which is overlain by Lower Cretaceous deposits containing pebbles of the Khevisdzhvar. Numerous outcrops of analogous intrusions, occurring in Middle Jurassic rocks, are known in Abkhasia; pebbles of intrusive rocks were found in the Kimmeridgian formation. A similar intrusion (Poladaur) was also found at the margin of the Loksky massif. On the basis of the available geologic data, these intrusions belong to the Bathonian.

In the geosynclinal volcanic sediments formation of the middle Eocene of Adzharia and Guria, there were found hypabyssal intrusions of syenite-diorite and quartz monzonite. Pebbles of these rocks were found in upper Eocene deposits; this made it possible to determine accurately the age of the intrusion as late middle Eocene. Hence, the emplacement of these intrusions is correlated to the Trialetsk tectonic phase.

Pegmatite veins, apparently associated with the above intrusions, are exposed at the surface along the Natanebi river, where they are called Vakisdzhvar pegmatites. They are composed of anorthoclase, plagioclase, biotite, actinolite, and magnetite. Apatite and pyrite are also present in significant amounts. The potassium-argon method was used to determine the age of biotite containing a little iron and 10.41 percent K_2O [18]. The content of radiogenic argon in biotite was determined twice. Both measurements gave almost the same results, and the age of biotite is approximately 30 million years, therefore, it was formed at the end of the Paleogene, which is the upper limit of the age of pegmatites and consequently of intrusions. Granitiod massifs are formed during the most intense tectonic phase which dislocates geosynclinal formations as a whole and influences marginal zones situated in the areas of resistant blocks. Besides, granitoid intrusions and intrusions of affiliated rocks form in the proper geosynclinal area (syenite-diorites of Adzharia and Guria), at the boundary with the resistant block, and also within this block (Khevisdzhvar and Poladaur intrusions). This conclusion may serve as a basis for assumptions concerning the age of similar granitoid intrusions in areas where possibility exists of establishing the upper age limit of their formation by the usual geologic methods.

On the basis of these considerations, some of the granitoids of the Dzirul and the Khrami massifs which occur in amphibolite and hornblende-biotite, biotite, and other schists, which represent the ancient metamorphosed volcanic sediments apparently belonging to the Precambrian or lower Paleozoic, are lower Paleozoic (Caledonian) in age [10, 11]. The same considerations led to the idea that the granitoids of the main Caucasian range, some of the granitoids of the Dzirul and the Khrami massifs, and granitoids of the Loksky massif, which occur in the lower Paleozoic and younger schists, quartzites, and marbles distributed on the main range within Abkhasia and probably in Verkhnyaya Racha (Mamisson pass), as well as in the Dzirul and the Loksky massifs, belong to the upper Paleozoic (Hercynian). It is possible that granitoids within the Diss formation and considered to be of Upper Jurassic age, actually are upper Paleozoic.

In the Dzirul massif [14] in the gorge of the Ninisistskhali river where this river joins the Chorat-Khevi river, close to the outcrop of the lower Paleozoic metamorphics, gray quartz diorite including a few small xenoliths of mica-plagioclase schist is cut by a vein of strongly metamorphosed porphyrite, which in turn is cut by a vein of pink granite. The porphyrite is calcitized, chloritized, silicified, and serpentinized. The enrichment in quartz was caused by the introducing granitoid. Apparently, between the emplacement of the quartz diorite and the pink granites was a great interval of time characterized by porphyrite effusives. That granitoids of two ages exist in the Dzirul massif is also confirmed by the presence in some places of granitized quartz diorites enriched in quartz and microcline. In these rocks introduced material, penetrating along intragranular seams, forms a fine-grained matrix; and minerals of the quartz diorite, mainly plagioclase, look like porphyritic inclusions. The injected material forms veins and inclusions. The same phenomenon is observed in the Khrami massif.

The graywacke-arkose sandstones, containing fragments of porphyrite and sandstone in the lower Paleozoic metamorphics in the Dzirul massif, indicates that, in addition to older granitoids, still older porphyrites existed, as well as unmetamorphosed sandstones whose outcrops apparently have been completely destroyed by the erosion.

Numerous pegmatite veins are associated with pink granitoids of the Dzirul massif. The microclinization of the more ancient granitoids (quartz diorite) is mainly associated with pink granitoids. Pegmatite veins are extensively distributed in the Macharula area. They are exposed in the watershed area between the Gezrula and the Macharula rivers, and occur either in gneissic-quartz diorites injected by pink granitoids, or in the quartz and microcline-enriched gabbro massif which cuts the schists. Pegmatites are mostly quartz, microcline-microperthite, and muscovite. Albite occurs in smaller amounts.

The absolute age of the pegmatites was determined from the outcrop at the Sarakhisgele brook, a right-bank tributary of the Gezrula river. Large, feathery muscovite crystals

containing 10.61 percent K_2O were analyzed. The arithmetic mean of three age determinations is 258 million years with a maximum deviation of 6.2 percent. Apparently, pegmatite, and consequently pink granitoids, are Carboniferous in age [18]. Thus, the assumption that the pink granitoids of the Dzirul massif are Hercynian, is justified. Gray granitoids are probably most likely they are Caledonian in age. Biotite contained in them was probably altered at the time of the Hercynian folding during the emplacement of pink granites.

A similar relation is observed on the northern slope of the Great Caucasus. According to G. D. Afansyev, the Urushten granitoids, occurring in lower Paleozoic rock are Caledonian. Pebbles occurring in Middle Devonian conglomerates are the same age. According to Sh. I. Dzhavakhishvili [19], these pebbles differ considerably from the gray microclinized granitoids, primarily by the absence of latticed microcline. However, they differ also from plagiogranites of the Urushten type by the presence of considerable amount of potash feldspar having no lattice texture. The existence of granitoids still older than Caledonian is indicated by the presence of fragments of latticed microcline, quartz, and acid plagioclase in the lower Paleozoic metamorphosed sediments of the Elbrus mine [19].

In order to determine the absolute age of younger granites, the so-called granites of the Main Range, investigations were made of muscovite from the pegmatite vein at the upper reaches of the Teberda river (the area of the Semenov-Bashi summit), which cuts granitoid containing relicts of schist. This vein is composed of quartz, latticed microcline-perthite, plagioclase from the albite group, muscovite, and occasionally biotite. The muscovite contains 9.81 percent K_2O. Radiogenic argon was measured twice and deviation from the mean was less than 2 percent. The age was determined to be 235 million years which corresponds to the middle Carboniferous [18]. It should be taken into consideration that the process of the formation of the pegmatite vein from which a sample was taken for investigation, as well as the process of potash metasomatism of the granitoids, are associated with the Hercynian granitoids, as in the Dzirul massif. It is possible that microclinized granitoids represent older rocks and most likely are associated with the Caledonian orogeny.

On the southern slope of the Great Caucasus, along the plane of the main overthrust of the crystalline core, several small intrusions, predominantly dacite, are exposed.

The crystalline massif was thrust over different horizons of Jurassic deposits. It can be assumed that this overthrust began in the Mesozoic, at the time when the upwarping of the Great Caucasus began. Numerous rejuvenations of the overthrust were associated with different phases of the folding. This is confirmed by the evidence of young movements recorded in the fold system of the southern slope. Hence, the main overthrust developed over a long period of time during the Mesozoic and Cenozoic. Formerly, the overthrust was considered to be of upper Tertiary age and consequently the dacite intrusions of Verkhnyaya Racha and Verkhnyaya Svanetiya were thought to be upper Pliocene. Dacites of the Sakur river gorge (Tianeti zone), interbedded with Lias deposits, were considered to be the same age.

If one considers the emplacement of dacite intrusions in the light of the above relation to presented ideas (that the emplacement of granitoids associated with the main tectonic phase which dislocated the geosyncline), then one must similarly consider their age. Evidently, this phase might be associated with the Mesozoic (Jurassic), as well as with a more recent time. Radioactive methods are a decisive factor in determining the age of intrusions of that type. The same could be said about the age of the Eldzhurtin granitoids.

As far as we know, geosynclines of the flysch type do not contain granitoids. There are many such cases, especially in Georgia, on the northern slope of the Great Caucasus, where the Geske formation, limestone, and other formations, were accumulated in the geosyncline. In 1956, Cretaceous flysch and limestone deposits in Czechoslovakia were observed by the author; no granite emplacements were seen. Usually, all non-volcanic geosynclinal formations not associated with granitoids, are only slightly metamorphosed, indicating that metamorphism is very often associated with granitoids. Here, the metamorphism is characterized by the transformation of the rock-forming minerals under the action of solutions.

THE EVOLUTION OF MAGMA IN DIFFERENT GEOTECTONIC REGIONS

The composition of igneous rocks differs in different geotectonic regions. The specific peculiarity of geosynclinal regions during the initial stages of their development is the basic composition of the emplaced magma. In some geosynclines, ultrabasic magma is first emplaced, then the basic magma-forming rocks of the gabbro-diabase-porphyrite composition is emplaced. The magmatic cycle ends in the formation of granitoids (in the case of the Caucasus, the Bathonian, Eocene, and other granitoids) associated with tectonic deformation of geosynclinal deposits [10, 11]. In Georgia such a sequence is recorded in the Dzirul massif, where serpentines are cut in many places by gabbroic rocks.

In marginal areas of the geosyncline, at the

boundary with resistant blocks, basic, acid and transitional types of effusives occur. It can be positively said that a specific characteristic of rigid areas is the presence of both basic and acid effusives, for basic magma assimilates rocks of acid composition upon contact over a long period of time. Also, acid rocks in the subcrustal zone can melt. For example, in the Bajocian volcanic sediments on the margin of the Dzirul massif on the right slope of the Chkherimel, a river valley, vast quartz porphyrite effusives are distributed. These are best exposed near Golatubani. The assimilation of rocks of granitoid composition by the basic magma is indicated by the presence of numerous quartz grains with signs of melting, in andesite-basalt rocks, as well as by the presence of microcline grains.

Acid effusives occur in the Dzirul massif, where magma was poured out under epicontinental, and partly under subaerial conditions which produced quartz porphyrites, quartz albitophyres and tuffs of these rocks (lower tuffites). At the same time in the Macharula area and in the Kviril, a river gorge, the acid effusives resulted in rocks of porphyrite and diabase types. In the Somkhetsk block area, a formation is found which is analogous in composition and apparently in age. In this area, the lower Cenomanian is represented by volcanics and calcareous deposits; the upper Cenomanian-Coniacian is characterized here by volcanics.

The composition of igneous rocks is again quartz-porphyres and quartz-alibtophyres. As a result of long and extensive effusive activity, especially through fissures, acid rocks may be completely lacking.

Southwest from the Kyugen-Kaya mountain (northern Caucasus) granites are overlain by raspberry-pink, meat-red and light-gray fine-grained Pliocene rhyolite with a lensing banded flow texture. These rocks contain numerous xenoliths of granitoids, some of which may be more than 0. 5 m in diameter.

The rhyolite is characterized by lensing or irregular forms which appear to be relicts of granite which were fully altered by lava. Probably these were brought up from the deeper parts of the crystalline basement. If this is true, then all the variety in composition of young effusive rocks of the Caucasus can be explained by the assimilation of various amounts of rocks from the substratum by the basalt magma, or even by magma of still more basic composition.

This idea is confirmed by the microsopic investigation of rocks whose composition is similar to rhyolite. The matrix of these rocks is glassy, heterogeneous, and taxitic; there are sections of a dark, almost black, glass, and some colorless sections which apparently represent melted granite xenoliths. Quantitative interrelations between these sections are different in different samples.

Experiments of well-known American scientists, O. F. Tuttle and N. L. Bowen indicate the possibility of a partial or complete melting of rocks of granite composition at comparatively low temperatures. Tuttle's results were presented at the XX International Geologic Congress in Mexico. These men found that at high vapor pressure (4,000 kilograms per square centimeter), a water-vapor content of 2 percent, and at 640°, about 20 percent of the granite melts. Under the same conditions, but with a water vapor content of 9 percent, granite melts completely. In the first case, the complete melting was recorded at 830°.

Extrapolating, the researchers came to the conclusion that, under conditions of pressure ranging from 8,000 to 10,000 kilograms per square centimeter, the melting point of rocks of granite composition will decrease to 590°. The author of this work thinks that such conditions are quite possible in effusive magmatic activity.

G. S. Dzotsenidze [9] considers the evolution of the chemical composition of magma with time in different geotectonic regions of Georgia. He is of the opinion that in the lower Lias in the geosyncline of the southern slope of the Great Caucasus and at margins of ancient massifs, acid magma resulted in the formation of quartz porphyrites and quartz albitophyres of the Dzirul and the Khrami massifs. In Middle Jurassic, the calcic-alkalic magma poured out in geosynclinal areas and the spilitic-porphyrite-diabase series of rocks was formed. During the Bathonian tectonic phase, granitoids (Khevisdzhvar and Abkhasian) were emplaced. Simultaneously, the residual, alkali-rich trachybasalt was separated from the geosynclinal magmatic basin. Within the Georgian block, an isolated magma chamber was formed which produced effusives in the Upper Jurassic (Kimmeridgian-Trinton formation).

The development of the Adzharo-Trialetsk geosyncline resembled the development of the Great Caucasus, but it was more complicated and there was a difference in time. In the Cretaceous (Albian, Cenomanian, and Turonian), in the basin of the Khrami river, and in the Paleocene (according to recent ideas, in the lower section of the lower Eocene), in the basin of the Algeti river, andesite and andesite-dacite lavas were poured out at the boundary between the geosyncline and the rigid blocks.

Magma associated with the Cretaceous (upper Aptian, Cenomanian, and lower Turonian) volcanism of the Adzharo-Trialetsk geosyncline,

in comparison with Middle Jurassic igneous rocks of the Sometsk block was somewhat more acid and more alkali-rich. Such magma composition resulted from the long existence of the geosyncline which was already formed in this area in the Middle Jurassic. Extensive calcic-alkalic effusives of Bajocian age resulted in the changing of composition of the relict magmatic basin. Cretaceous volcanics, as a whole, are of the spilitic-porphyrite type. Magma of the middle Eocene is basaltic, but, in comparison with the Middle Jurassic magma, is alkali-rich.

In the Cretaceous, an isolated magma chamber was formed under the Georgian block and produced in the Turonian age an analcite-picrite-basalt-phonolite series. Such compositions are probably explained by the assimilation of Lower Cretaceous limestones by the magma of the spilitic composition.

The second magma chamber was formed just before the upper Eocene. The magma was still more alkali-rich and, therefore, the magma in the upper Eocene chamber acquired a trachyandesitic composition. The later differentiation under quiet conditions resulted in the formation of a potassium-basalt-tephrite-trachyte series. Tectonic phases which resulted in the dislocation of the Cretaceous-Eocene were accompanied by the emplacement of granitoid intrusions.

GENESIS OF GRANITOIDS AND THEIR ASSOCIATION WITH THE ORE FORMATION

Of a great importance for the lower structural horizons of the Caucasian territory is the process of metasomatic granitization occurring under the action of the high-temperature leucocratic material. This material consists of predominately alkalis, silicon, and water supplied under high pressure, together or separately, and resulting in the formation of granite magma. Metasomatic granites fill the shrinkage voids of cooling crystallizing magma.

In upper structural horizons, the emplacement of the granite magma results in the formation of magmatic granitoids; processes of assimilation and contamination generally occur here. Ore-bearing solutions are associated both with processes of granitization and with processes of the intrusion of magmatic masses penetrating along tectonic fissures into the upper structural zones. In addition, ore formation apparently results from the penetration of mineralizing solutions coming directly from depth and having no direct connection with the developing granitoids.

This author shares Kh. M. Abdulayev's opinion that magmatic differentiation was of little significance in the formation of granitoid rocks. It is doubtful if any geologist engaged in studies of igneous rocks can present positive evidence of differentiation leading to the formation of granitoids. Therefore, this author feels that N. P. Vasilkovsky's criticism [3] of Abdulayev is unjust.

Kti-Teberda scheelite deposits at the upper reaches of the Aksaut river, which are associated with gneisses and schists are an example of an obvious association of the ore occurrence with ancient granitoids. Scheelite deposits are commonly found in quartz-feldspar and quartz veins which granitize host rocks.

On the southern slope of the Great Caucasus, different types of rare-metal ores are associated with recent small intrusions controlled by regional fracturing (the main overthrust).

A direct association can be observed in deposits of the high-temperature type, for example in the Tsurungal area (Verkhnyaya Svanetiya) and in the Karobi area (Verkhnyaya Racha). G. I. Kharashvili [20] noted two phases of mineralization in the Karobi area. The first phase was rich in high-temperature ore minerals. Mineralization began with dacite emplacement and continued through complete crystallization. The dacite is impregnated with molybdenite. Much later, the second phase occurred at lower temperature; slightly ore-bearing quartz penetrated fissures in the dacite. Later phases of mineralization produced in Verkhnyaya Racha a series of well-known rare-metal deposits (Notsara, Sagebi, Zopkhito, Kodis-Dziri, Lukhumi, and others) of the meso- and epithermal type. These occur at considerable distances from the intrusive bodies. A direct association of ore bodies with granitoids cannot be clearly seen. However, an association can be established on the basis of the time relations between the formation of ore bodies and intrusions (if the latter are found) and on the basis of the association of ore bodies and intrusions with the same geotectonic zone.

The detailed study of the composition of the assumed parental intrusive rock might be of great help; accessories should be investigated in order to find elements corresponding to elements of the ore bodies. Of great significance also can be the determination of the absolute age of ores and intrusive rocks. If it is not possible to carry out such investigations, then Abdullayev's statement [1] concerning the direct association of ore bodies with a certain neighboring intrusion, is hazardous.

Many ore deposits are known in Georgia, but these ores could be directly associated with any intrusions. Some of these deposits are the Madneul pyrite deposits, the Kvaysin polymetallic deposits, and the Poladaur iron-ore deposits. The Urup pyrite deposits occur in Devonian schists in an area of no granitoid intrusions. By analogy with the Urals, some geologists associate these deposits genetically with quartz albitophyre effusives. In addition to albitophyres and their tuffs, albitized and chloritized diabasic porphyrites and their tuffs are also present. The ore body is very different in its composition and

texture in different sections. In the Skalistaya section, ore penetrates schists along the stratification planes, like migmatites; this is characteristic for areas granitized metasomatically. In other sections, massive ores occur. Their origin may be compared to the origin of granite massifs in areas where the process of metasomatic granitization is in a higher stage of development.

It seems that pyrite deposits were formed as the result of metasomatic action of a highly concentrated ore-bearing solution on the host rocks; these solutions act like alkali-rich granitizing solutions. The entire process apparently took place much later than the formation of host rocks, as a whole. Apparently it was synchronous with the tectonic phase which dislocated the Devonian (?) volcanics.

The absence of granite massifs in this formation leads to the question of whether it would not be possible that sometimes, instead of alkali-rich granitizing solutions, the ore-rich solutions rose from the depths in the geosynclinal areas which, being very active, form metasomatic ore bodies. The Poladaur iron-ore deposits and Madneul pyrite deposits in the Boeniss district of Georgia are, apparently, of such an origin.

Field observations and microscope studies on the actions and reactions of potassium, sodium, and silicon, which result in metasomatic granitization, has led researchers to think that some other elements, including ores, can also be introduced by solutions.

The above considerations on the formation of granitoids and associated ores based on the material of the Caucasus, are probably oversimplified. Phenomena developing in nature are apparently much more complicated. The purpose of these suggestions is to outline possible directions for further research in this very interesting field.

REFERENCES

1. Abdullayev, Kh. M., GENETICHESKAYA SVYAZ ORUDENENIYA S GRANITOIDNYMI INTRUZIYAMI [GENETIC CORRELATION OF MINERALIZATION WITH GRANITOID INTRUSIONS]: Gosgeoltekhizdat, 1954.

2. Afanasyev, G. D., NEKOTORYYE OSOBENNOSTI RAZVITIYA MAGMATIZMA SEVERO-KAVKAZSKOY SKLADCHATOY OBLASTI [SOME PECULIARITIES OF THE DEVELOPMENT OF MAGMATIC ACTIVITY IN THE NORTHERN CAUCASUS FOLD REGION]: Akademiya Nauk SSSR, Izvestiya, Seriya Geologicheskaya, 1952, no. 4.

3. Vasilkovsky, N. P., O KNIGE Kh. M. ABDULLAYEVA +GENETICHESKAYA SVYAZ ORUDENENIYA S GRANITOIDNYMI INTRUZIYAMI" [ON Km. M. ABDULLAYEV'S BOOK "GENETIC CORRELATION OF MINERALIZATION WITH GRANITOID INTRUSIONS"]: Akademiya Nauk SSSR, Izvestiya, Seriya Geologicheskaya, 1956, no. 2.

4. Gamkrelidze, A. D., GEOLOGICHESKOYE STROYENYIYE ADZHARO-TRIALETSKOY SKLADCHATOY SISTEMY [GEOLOGIC STRUCTURE OF THE ADZHARO-TRIALETSKOY FOLD SYSTEM]: Akademiya Nauk, Grus, SSSR, Izd.-vo, 1949.

5. Gerasimov, A. P., TESHENITY S. R. IORI (KAKHETIYA) [TESHENITE NEAR IORI RIVER]: GERU VSNKH SSSR, Trudy, 1931, no. 29.

6. Dzhanelidze, A. I., GEOLOGICHESKIYE NABLYUDENIYA V OKRIBE [GEOLOGICAL OBSERVATIONS IN OKRIBE]: Akademiya Nauk SSSR, Gruz. filial, Izvestiya, 1940.

7. ________, TEORIYA OROGENETICHESKIKH FAZ SEGODNYA (NA GRUZINSKOM YAZYE [CURRENT THEORIES ON OROGENETIC PHASES (IN THE GEORGIAN LANGUAGE)]: Tbilissk, gos. in-ta im. Stalina, Trudy, v. 46, 1952.

8. ________, KONTINENTY I IKH PROISKHOZHDENIYE (NA GRUZINSKOM YAZYKE) [CONTINENTS AND THEIR ORIGIN (IN THE GEORGIAN LANGUAGE)]: Akademiya Nauk, Gruz. SSR, Izvestiya-vo, 1955.

9. Dzotsenidze, G. S., DOMIOTSENOVY EFFUZIVNY VULKANIZM GRUZII [EVALUATION OF EFFUSIVE VOLCANISM IN GEORGIA]: Akademiya Nauk Gruz. SSR, Izvestiya-vo, 1942.

10. Zaridze, G. M., ZAKONOMERNOSTI RAZVITIYA VULKANIZMA GRUZII [THE DEVELOPMENT OF VOLCANISM IN GEORGIA IN ACCORDANCE WITH ESTABLISHED THEORY]: Gostekhizdat, GSSR, 1947.

11. Zaridze, G. M., and N. F. Tatrishvili, VVEDENIYE V MAGMATICHESKUYU GEOLOGIYU GRUZII [INTRUDUCTION TO THE MAGMATIC GEOLOGY OF GEORGIA]: Gostekhizdat, GSSR, 1947.

12. ________, O VOZRASTE TSALKSKOGO LAVOVOGO KOMPLEKSA [ON THE QUESTION OF THE TSALKSK LAVA COMPLEX]: Akademiya Nauk SSSR, Doklady, v. 59, no. 1, 1948.

13. ________, OB INTRUZIVNYKH PORODAKH I IKH EFFUZIVNYKH ANALOGAKH [ON INTRUSIVE ROCKS AND THEIR EFFUSIVE ANALOGUES]: Akademiya Nauk, SSSR, Soobshch, v. 10, no. 6, 1949.

14. Zaridze, G. N., and N. F. Tatrishvili, O VOZRASTNYKH VZAIMOOTNOSHENIYAKH I GENEZISE DREVNIKH KRISTALLICHESKIKH POROD DZIRULSKOGO MASSIVA [ON THE AGE CORRELATION AND GENESIS OF ANCIENT CRYSTALLINE ROCKS OF THE DZIRUL MASSIF]: Geol. in-ta, Trudy, Seriya Mineral-petrografich, v. 3. 1953.

15. ______________, O VOZRASTE I GENEZISE DREVNIKH GRANITOIDNYKH POROD KHRAMSKOGO MASSIVA [ON THE AGE AND ORIGIN OF THE ANCIENT GRANITOID ROCKS OF THE KHRAMSK MASSIF]: Akademiya Nauk SSSR, Izvestiya, Seriya Geologicheskaya, v. 3, 1953.

16. ______________, O VOZRASTNYKH VZAIMOOTNOSHENIYAKH I GENEZISE DREVNIKH KRISTALLICHESKIKH POROD LOKSKOGO MASSIVA [ON THE AGE CORRELATION AND ORIGIN OF ANCIENT CRYSTALLINE ROCKS OF THE LOKSK MASSIF]: Akademiya Nauk SSSR, Izd-vo, Voprozy petrografii i mineralogii, v. 1, 1953.

17. Skhirtladze, N. I., TESHENITOVAYA FORMATSIYA ZAPADNOY GRUZII (NA GRUZ. YAZYKE) [INFORMATION ON FORMATIONS IN WESTERN GEORGIA (IN THE GEORGIAN LANGUAGE)]: Akademiya Nauk SSSR, Trudy Geol. in-ta Seriya Mineral.-petrografich, v. 1, 1943.

18. Rubinshteyn, M. M., OB ABSOLYUTNOM VOZRASTE NEKOTORYKH MAGMATICHESKIKH OBRAZOVANY GRUZII [ON THE ABSOLUTE AGE OF MAGMATIC ROCKS IN GEORGIA]: Akademiya Nauk GSSR, Soobshch., v. 16, no. 6, 1955.

19. Tatrishvili, N. F., and Sh. I. Dzhavakhishvili, PALEOZOY KLUKHORSKOGO RAYONA [THE PALEOZOIC OF THE KLUKHORSK REGION]: Akademiya Nauk GSSR, Trudy, in-ta geol. i miner., 1955.

20. Kharashvili, G. I., GEOLOGO-PETROGRAFICHESKY OCHERK KAROBSKOGO MESTOROZHDENIYA I USLOVIYA YEGO FORMIROVANIYA [GEOLOGIC AND PETROGRAPHIC OUTLINE OF THE KOROBSK DEPOSIT AND THE CONDITIONS OF ITS FORMATION]: Akademiya Nauk SSSR, Izvestiya, Seriya Geologicheskaya, 1939, no. 6.

INHERITED TRENDS IN THE DEVELOPMENT OF THE PALEOZOIC STRUCTURES OF THE SARYSU-TENIZ UPLIFT (CENTRAL KAZAKHSTAN)[1]

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ABSTRACT

The history of the development of the structural forms in the Sarysu-Teniz uplift, central Kazakhstan, is expressed in the lower Caledonian, late Caledonian, and upper Hercynian. The first period is characterized by meridional folding which resulted in the formation of the Paleozoic geosyncline. In the second period, development of the geosyncline ceased and volcanic activity, both effusive and intrusive, was intense. The principal tectonic elements of the Devonian (late Caledonian) were inherited from the lower Paleozoic. In Middle Devonian, extensive faulting occurred. These "newborn" Hercynian structures, developed on older Caledonian structures, were not determinative for this region. During the third period of tectonic deformation, large west and northwest-trending fold-blocks, called graben-synclines and horst-anticlines, were formed. Because the structural features of the first two periods are structurally similar and trend in the same direction, the differing third period is superimposed disconcordantly.

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The intersection of the Caledonian and Hercynian folds in central Kazakhstan was first recorded by P. L. Merkulov and A. Ye. Repkina [8] and others [1, 4, 6, 7, 9, and 13]. Merkulov and Repkina indicated that sharp azimuthal unconformity (deflection in strikes of tectonic structures of different ages, but not intersection of beds on axes of folds which is the usual phenomenon related to unconformities) in the area of the Sarysu-Teniz watershed is exhibited at the intersection of submeridional folds formed by west- and northwest-striking lower Paleozoic sediments and Devonian effusives. N. G. Kassin [4, 5] advanced a theoretical basis for such intersections of fold systems which, in his opinion, are typical for vast areas in the Akmolinsk and Karaganda regions. He supported his conclusions by diagrams of the tectonic framework and by paleographic maps.

In 1938, N. S. Shatskiy published an article on the tectonics of central Kazakhstan. This work is of great importance and presents a new interpretation of the geology and tectonics of the area [13]. Shatskiy's views are based on the concept of inherited characteristics of great anticlinal and synclinal structures forming the folded Paleozoic foundation of central Kazakhstan. Shatskiy criticizes Kassin's views on the tectonics of Kazakhstan and denies the possibility of intersection of Caledonian folds.

However, it should be mentioned that these works consider the problem of intersection of folded structures, but present no data on deformation involving fracturing and on stratigraphic relationships associated with these deformations.

In later works by P. N. Kropotkin and G. I. Nemkov which treat the problem under discussion [6, 9], as well as in works by A. V. Volin and R. A. Borukayiev [2, 3], the appearance of certain of the upper Paleozoic tectonic structures of central Kazakhstan is associated with deformation involving fractures. These graben and horst structures are characterized by discordant superimposition and intersection with older Precambrian and lower Paleozoic folds.

The geology and types of structural forms of the Sarysu-Teniz watershed (Sarysu-Teniz uplift), were described in detail by A. A. Bogdanov [1]. Deformations of different ages, involving folding and fracturing and governing the final structure of the Sarysu-Teniz uplift as a system of linear fault-folds (graben-synclines and horst-anticlines) are considered characteristic. Bogdanov also describes the pattern made by intersection of structures in the area with tectonic elements of bordering regions. Discussing the interrelation of the Caledonian and Hercynian folds the author indicates that "the most important specific feature of the tectonics of the Sarysu-Teniz uplift is not the intersection of folded systems of different ages, characterized by similar mechanism of formation, but that the upper Paleozoic linear fault-folds are superimposed on Precambrian and lower Paleozoic linear folds at right angles" [1].

Thus, at the present time, the nature of intersecting tectonic structures in the Sarysu-Teniz

[1] Translated from Cherty unasledovannosti v razvitii Paleozoyskikh struktur Sarysu-Tenizskogo podnyatiya (Tsentralny Kazakhstan): Sovetskaya Geologiya, 1958, no. 4.

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uplift is well established and the extension of this phenomena has been generally described.

However, many facets of this interesting problem are still unexplained. For example, it is known, that the azimuthal unconformity is manifested by the intersection of Cambrian, Ordovician, and Silurian linear folds with graben-synclines in calcareous Famennian and lower Carboniferous sediments. The Devonian volcanics of variable composition have an intermediate position between these clearly defined structures. There is little data in the literature on stratigraphic relationships within the Devonian complex. Little is known about its relation to ancient folds, on one side, and the upper Paleozoic block-faulted structures, on the other side. Merkulov, Repkina, and Kassin mentioned the intersection of the lower Paleozoic and Devonian folds and the fact that the crustal architecture of the country was basically rebuilt at the end of the Silurian and before the beginning of the Devonian. Later, Kropotkin advanced an assumption that the Hercynian folds of the Sarysu-Teniz uplift "originated from horst and grabens which in the Devonian period discordantly dissected the area of the Caledonian folding" [6]. Lava flows were associated with these deep-seated fractures.

At present, geologists studying the Sarysu-Teniz uplift accept the concept that the Devonian structures are part of the Hercynian tectonic elements. For example, O. A. Mazarovich in his latest article [7] writes: "Devonian and Carboniferous deposits were deformed in different ways. They form brachyfolds, [Ed. : a term used in the U. S. S. R. to designate a long, narrow fold], domes, graben-synclines, and horst-anticlines, which, with a sharp azimuthal discordance, superimpose linear folds of the ancient folded foundation and form the Hercynian structural stage".

In our opinion, it is natural that questions arise concerning the existence of certain elements of inheritance in the history of folds of the Sarysu-Teniz uplift in the lower Paleozoic and Devonian. This is confirmed by the continuous geologic column in the central and eastern areas of the uplift and by the absence of great stratigraphic disconformities. Thus, latitudinal block faulting was superimposed on the lower Paleozoic folds, and continued simultaneously with the further development of these folds. Hence, we may distinguish in the Devonian, the structures of the Caledonian tectogene, as well as the elements of Hercynian tectonic structures and of a new tectonic framework.

The peculiarities of the tectonics of this region can be clarified by the consideration of the following: 1) the study of the contacts of the Devonian rocks with older rocks especially the location of the lower boundary of the given structural complex and the type of unconformity which exists at its base; 2) the description of Devonian folds in different tectonic zones; 3) the study of regularities in the location of Devonian volcanic facies and the study of their dependence on certain tectonic elements of primary order; 4) the description of Caledonian structures in the Devonian and the clarification of their connection with Devonian forms; and 5) discovery of new Hercynian tectonic elements and their position in relation to the present structure of the folded area. In the present work, the author outlines possible methods of solving this complicated problem.

THE PALEOZOIC STRUCTURE OF THE SARYSU-TENIZ UPLIFT

The Sarysu-Teniz uplift is a large anticlinal structure in central Kazakhstan and is situated between the upper Paleozoic Teniz and Dzhezkazgansk depressions. It is composed of rocks of different ages, from Precambrian up to and including middle Carboniferous with considerable preponderance of Devonian and lower Carboniferous rocks. The uplift is dissected by a series of extensive faults which form north-west striking graben-synclines and horst-anticlines commonly with peculiar shpaes. The length of these linear fault-folds is more than 100 km, the width ranges from 5 to 15 km.

These are three structural stages evident within the Sarysu-Teniz uplift, which are associated with three separate periods of the geologic history of the area.

The upper(properly Hercynian) structural stage is represented by graben-synclines built of Upper Devonian and lower Carboniferous calcareous deposits 2,500 m thick; Famennian, Turonian, and Visean sediments can be distinguished.

Visean sediments are represented by limestones, marbles, and terrigenous deposits. Namurian and middle Carboniferous clastic rocks are found in a graben-syncline in the center of the Sarysu-Teniz uplift and at the margins near the Teniz and Dzhekazgansk depressions.

Graben-synclines usually have steep flanks and flat bottoms with a depth (along the bottom of Famennian sediments) as much as 3,000 m. In their central portions, complicated folds of secondary order were developed. Northwest-striking fractures separate graben-synclines from horst-anticlines. The asymmetry of the structures of the Sarysu-Teniz uplift is caused by variation of magnitude of movement along the faults. Thus, tilted or one-sided horst and grabens are distinguished, in which the bounding fractures disappear along the strike or develop at depth and do not appear on the surface. Folds with truncated limbs also are common, as are recumbent folds. Horst-anticlines of the Sarysu-Teniz uplift are composed of rocks of two older structural stages.

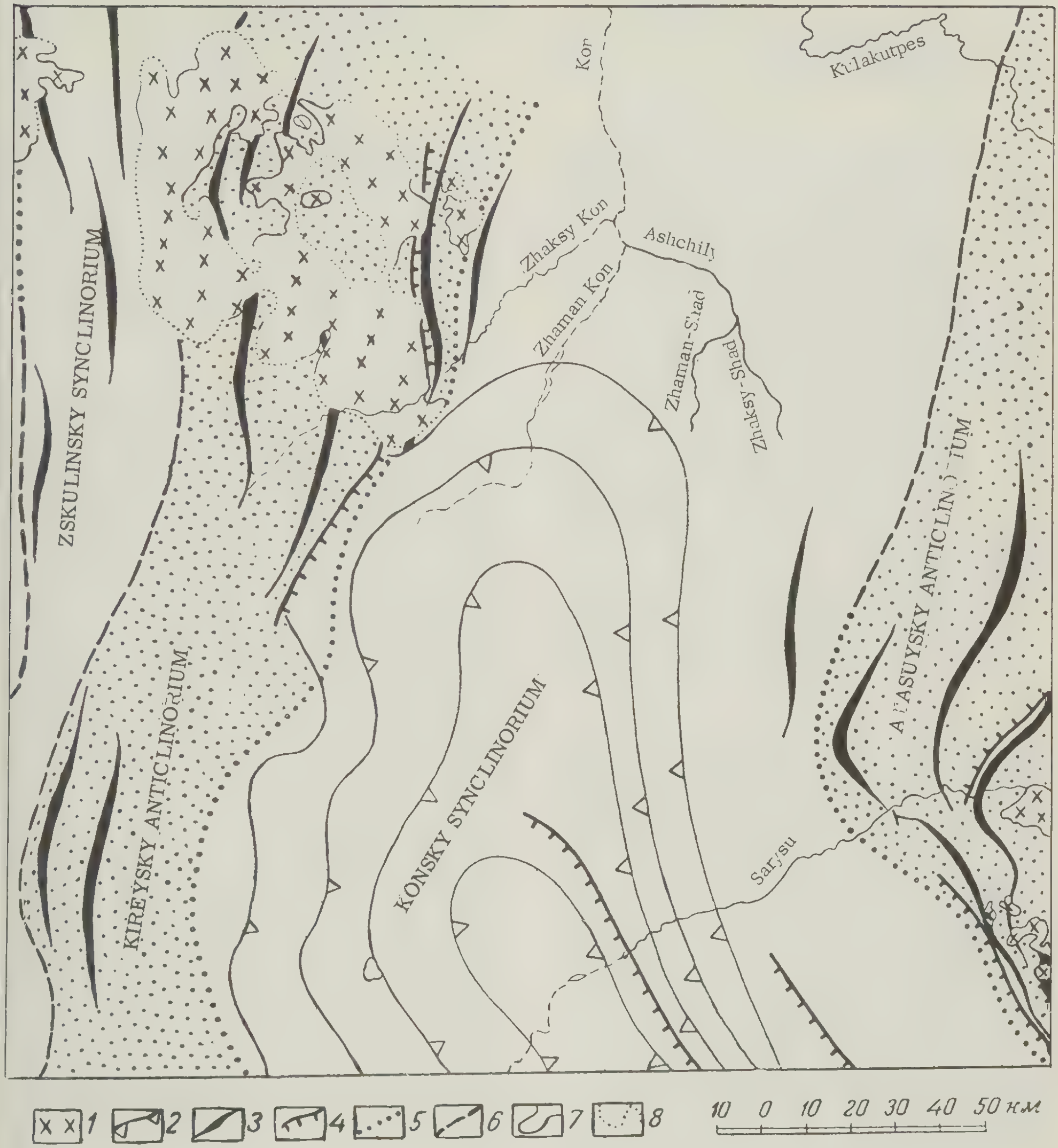

FIGURE 1. Tectonic frameworks of the central area of the Sarysu-Teniz uplift at the end of the Silurian (according to A.A. Bogdanov and A. Ye. Mikhailov).

1. Ordovician intrusions; 2. depressions filled with Silurian deposits; 3. axes of great anticlines; 4. main lower Paleozoic fractures; 5. boundary between structural elements; 6. inferred boundary between structural elements; 7. boundaries of intrusions; 8. assumed boundaries of intrusions.

The middle (Devonian or late Caledonian) structural stage is characterized by Devonian volcanic rocks with considerable facies variation in both vertical and horizontal directions. Devonian rocks are divided into two sections: the lower, composed of Lower and Middle Devonian rocks; the upper, separated from the underlying rocks by regional unconformity and including Middle Devonian rocks and the Frasnian stage of the Upper Devonian.

The lower section, with a total thickness up to 5,000 m consists of a lower sequence of conglomerates and sandstones, or andesitic porphyrites (the Porphyrites formation), and an upper sequence of sandstone and volcanics which are composed of acid effusives of varied composition and tuffs (the Albitophyric formation).

The upper (Zhaksykon) section is composed of as much as 3,000 m of various volcanic rocks interstratified with conglomerates and sandstones. Leucocratic granites and granodiorites with a slightly developed vein facies, possibly Middle Devonian, also occur. Devonian folds are either vast, flat, isometric or elongated brachyfolds and domes, distributed in areas where the ancient underlying foundation is well consolidated and denuded, or linear folds associated with mobile tectonic zones with a tendency toward downwarping. Where the fault-folds of the upper stage were stripped away, these tectonic forms, resulting from deformation involving fracturing, might also be found in the Devonian structure. Thus, the criteria for distinguishing an independent Devonian structural stage is 1) the presence of the peculiar Porphyrites formation [7, 10, 11], 2) the presence of regional unconformities at the base and the top of this formation, and 3) the existence of certain forms of stratigraphic relationships.

The lower Caledonian structural stage embraces folds formed by Precambrian and lower Paleozoic rocks cut by granitoid intrusions. In vast areas, the Caledonian structure of the Sarysu-Teniz uplift is dissected by later tectonic movements, has subsided considerably and is overlain by younger deposits; thus, lower Paleozoic rocks are exposed only as separate fragments in the arches of horst-anticlines. This stage is characterized by the presence of typical Precambrian geosynclinal formations (various crystalline and metamorphic schists) and by Upper Cambrian, Ordovician, and Silurian rocks, represented by beds of great thickness (up to 6,000 m) of conglomerates, sandstones, siliceous sediments, and various volcanic acid and intermediate rocks. Unlike the upper paleozoic sediments, these rocks are intensively metamorphosed and altered to green schist.

Precambrian and lower Paleozoic rocks are deformed into a system of linear folds characterized by meridional and submeridional strikes within the Sarysu-Teniz uplift and west of it, in the Ulutau anticlinorium. In the east, in the region of the Atasuysky and Teturmas anticlinoriums, the folds strike northeast and east.

Figure 1 presents the tectonic framework of the central area of the Sarysu-Teniz uplift at the end of the lower Paleozoic. The northwestern and western parts of the area are occupied by the vast Kireysky anticlinorium whose core consists of Precambrian and Cambrian deposits, and its flanks of Ordovician rocks. To the east is the Konsky synclinorium, which is filled with Silurian deposits. Both structures strike submeridionally and north-northeast.

HORST-ANTICLINES
Crustal Architecture of Lower-Middle Devonian Rocks

Contacts of lower Paleozoic and Devonian rocks in the central part of the Sarysu-Teniz uplift, on the eastern flank of the Kireysky anticlinorium, and in the area of the Konsky Synclinorium, where the azimuthal unconformity between Caledonian and Hercynian structures is clearly exhibited, were studied.

Of greatest interest is the so-called Kyzyemchek anticline (the basin of the Kankarasu river) which was described by Merkulov and Repkina as an example of a structure in which the azimuthal unconformity (up to 90°) between the Lower-Middle Devonian effusives and the Upper Silurian rocks can be directly observed. The Kyzyemchek anticline (horst-anticline) extends across Sarysu-Teniz uplift for 110 km; the maximum width of the structure is 15 or 20 km. In the arch of this narrow fold some Ordovician but mostly Silurian rocks, which have a submeridional strike, are exposed. Devonian effusives cling to outcrops of lower Paleozoic rocks; these effusives are distributed in the limbs of the structure and their clearly exhibited stripes extend in the latitudinal direction.

From 1953 to 1956, the author, on the basis of investigations in the area under discussion, compiled the geologic map which gives a new interpretation of the principal problems of the geology of the area (fig. 2). At the bottom of the geologic column, Silurian deposits are overlain unconformably by the lower section of the Lower Devonian series, which is represented by interstratified conglomerates, sandstones, siltstones, and acid tuff. These rocks are overlain, also unconformably, by acid effusives and tuff of the so-called Albitophyric formation which corresponds to the upper section of the Lower Devonian series.

Thus, Silurian and Devonian rocks compose a large southwest-dipping monocline with two great unconformities, the described structure is broken into east-striking blocks by oblique faults. On the surface of these deformations, Devonian Albitophyric effusives lie directly on Silurian rocks, forming the so-called tectonic contact, which formerly was held to be a contact with the azimuthal unconformity.

Interrelations of rocks, similar to those described above, are also observed in other areas of the Kyzyemchek Horst-anticline. Thus, in a western dome, the lower sandstone formation

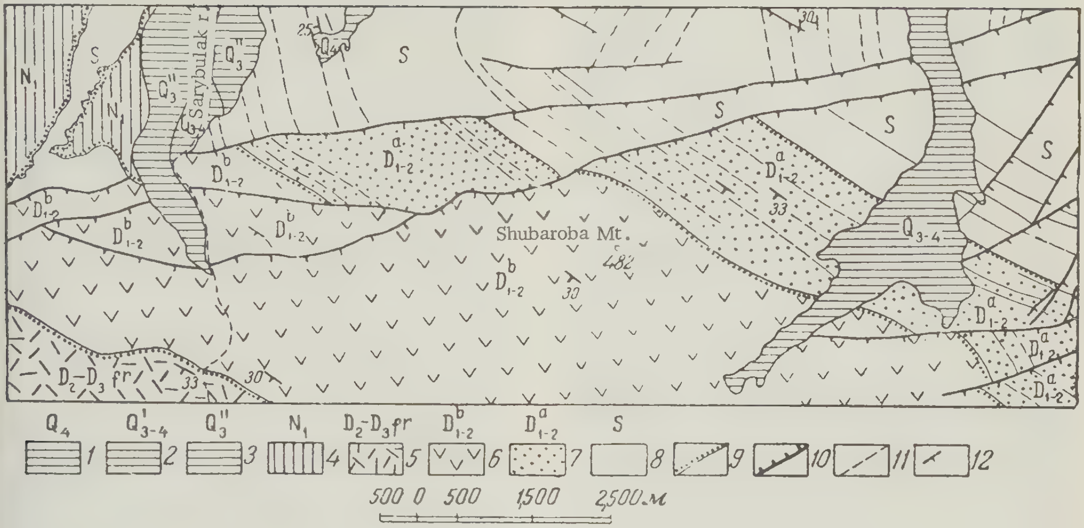

FIGURE 2. Geologic map of the part of the Kyzyemchek horst-anticline (The Kankarasu river) 1, 2, 3, and 4. unconsolidated Cenozoic deposits; 5. sedimentary volcanic deposits of the Middle Devonian and of the Frasnian stage of the Upper Devonian; 6. volcanic rocks of the Lower-Middle Devonian (Albitophyric formation); 8. Silurian deposits; 9. geologic boundaries of discordant bedding; 10. deformations involving fracturing; 11. strikes of strata, established from air photographs and traced; 12. dip-strike symbols.

belonging to the Devonian period overlies Silurian deposits unconformably, but have the same strike. In another tectonic zone, on the eastern limb of the ancient Kireysky anticlinorium, which is exposed within the horst-anticline of the same name, as well as in a small fold adjacent on the south, interesting contacts of the Lower and Upper Devonian series with the underlying lower Paleozoic deposits were observed. Unlike the previously discussed case, the stratigraphic hiatus is much longer. Upper Ordovician agglomerate deposits striking southwest are overlain unconformably by Lower-Middle Devonian sandstones and conglomerates. Devonian rocks form a small brachyfold dissected by faults. West of this area, lower Paleozoic rocks are overlain by deposits of the Zhaksykon series. In many tectonic zones, this unconformity is exhibited more sharply than the unconformity at the base of the Devonian system, especially where the Lower Devonian series is absent from the geologic column. Thus, sections are observed on the limb of the Kireysky anticlinorium, in which the axes of superimposed synclinal structures of the Middle-Upper Devonian intersect the underlying older rocks at angles up to 90°. In many cases there is little or no difference in the strikes of the unconformable complexes.

Further south near Terekti mountain, on the right bank of the Sarysu river, are other lower Paleozoic structures. This tectonic area, which presents the continuation of the Kireysky anticlinorium, is similar to the northern part with regard to the general type of geologic column, as well as with regard to the intersection of structural elements. Beds of varied lithologic composition resting on the base of the Devonian system, are separated from the underlying sediments by regional unconformity. The framework of Devonian structures is connected with the framework of folding of the lower Paleozoic foundation. Structures in this area are generally similar to structures of the Kireysky horst-anticline and give no new insights.

In the description of the Paleozoic structure of the Sarysu-Teniz uplift, it was stated that the Devonian folds of this structure are different in different tectonic zones. The superimposed structures of the brachyfold type are common in regions of Caledonian structure. Such folds are recorded within the arch of the Kireysky anticlinorium, on its eastern flank, and to the west, on the margins of the Ulutau anticlinorium, where Devonian sediments often rest on the Precambrian basement. Other types of Devonian rocks and structures are characteristic for the eastern part of the Sarysu-Teniz uplift which is situated within the vast Caledonian Kon synclinorium, where thicknesses of the Devonian volcanic deposits attain their maximum and lavas greatly predominate in cross

sections.

In general, the Kon synclinorium reflects the mobile state of the earth's crust and is the area of the greatest development of Devonian volcanism. The meridional or submeridional strike of large Devonian structures and separate folds is recorded in this tectonic zone [7]; Devonian volcanic facies strike in the same direction, and the most abrupt facies change usually occurs in an east-west direction. The Devonian rocks are much more intensely folded here than in areas to the west. Evidently, the Kon syncline is transitory between irregular folding and complete geosynclinal folding. The exposures of lower Paleozoic rocks with submeridional strike are limited in the Kon structure and Devonian sediments overlie them with sharp unconformity. Graben-synclines are in a discordant position in relation to lower Paleozoic and Devonian folds, marking the existence of the basic azimuthal unconformity between the Caledonian (lower Paleozoic) and Hercynian (Carboniferous) structures.

The following conclusions can be made on the basis of the above material:

1. Within the Sarysu-Teniz uplift the Devonian tectonic structures may be classified as simple brachyfolds, typical for the western and central parts of the uplift, and the almost linear folds which are developed in the east, in the area of the lower Paleozoic Konsky synclinorium. The first type of fold is associated with the consolidated and denuded Caledonian foundation of the region; the second type is distributed in the mobile tectonic region, which clearly exhibits a tendency to downwarp.

2. Devonian rocks are separated from the underlying structures by the regional unconformity, e. g. on contacts between the folded Precambrian and lower Paleozoic rocks and Zhaksykon rocks. This unconformity is not as sharp on contacts of the Silurian and Lower Devonian deposits where the successive development is stressed by the similarity of lithologic composition of the rocks.

3. A difference between the strikes of the lower Paleozoic and Devonian strata is usually recorded in areas of the closing of folds. Discordant interrelations may be also marked where the usually east-west strikes of Devonian exposures in horst-anticlines are compared with submeridional folds of older rocks. Direct contacts between the first and the latter are, as a rule, tectonic.

4. A proper azimuthal unconformity between the Devonian and the older structures, characterized by the difference in strikes of axis of folds, is generally absent; thus, the material presented suggests the idea of inherited character of tectonic framework and forms of the lower Paleozoic and the Devonian.

As stated before, to support this concept, it is necessary to analyze peculiarities in the distribution of the Devonian facies and their relation to the Caledonian tectonic structures. These are more discernable in the central part of the Sarysu-Teniz uplift: the area of the Kireysky anticlinorium, its eastern slope, and the Konsky synclinorium, where the intersection of the Caledonian and Hercynian folds is most clearly exhibited.

Association of the Lower-Middle Devonian Facies with Caledonian Tectonic Structures

The Kireysky and Kumkul horst-anticlines which extend from the middle reaches of the Zhaksy-Kon river to the Zhaman-Shad river, on the basis of their interrelationship with the Caledonian structure, can be divided into three sections which, from west to east, are as follows: 1) the western part of the horst-anticlines lies in the arch of the Kireysky anticlinorium; 2) the central part corresponds to the eastern flank of the anticlinorium; and 3) the eastern margin of horst-anticlines is in the area of the Konsky synclinorium. In the west, the lower Paleozoic rocks are exposed; the lower Devonian is not characteristic for this tectonic area, and Devonian deposits seem to be represented here by volcanic and sedimentary rocks belonging to the Zhaksykon series.

In the Kireysky horst-anticline, the lower section of the Lower-Middle Devonian exposed on the flank of the anticline along the left bank of the Zhaksy-Kon river is represented by interstratified conglomerates and sandstones with few beds of andesitic porphyries and albitophyres. The upper section of the lower series is composed of sandstones and acid tuff, which are rare and occur only near the top of the section. Along the strike of the horst-anticline, the facies of these sediments change strikingly within a short distance. Along the right bank of the Zhasky-Kon river, the lower section is represented by sandstones; conglomerates are missing. In the Kumkul horst-antilcine, to the south, exposures of an equivalent section along the Zhaksy-Kon river are graywacke sandstones. Still further to the east, porphyrite rocks appear in the lower section. Finally, in the Kon structure, on the right bank of the Zhaksy-Shad river, the lower middle Devonian andesitic porphyrites form a massif; no sedimentary rocks are present.

Facies changes in the upper section are still more striking; at a distance of 14 km east of the Zhaksy-Kon river, sandstones are replaced by andesitic porphyrites, albitophyres, and liparitic porphyries and by tuff of these compositions. Further along the strike of the horst-

anticline, on the right bank of Zhaman-Kon river, rhyolitic porphyries and tuffs are exposed, and farther east, near the Zhaksy-Shad river, various volcanic rocks, mostly lavas, are exposed.

In addition to the described Devonian sedimentary and volcanic facies, changes in the Kirey Horst-anticline, significant alterations of the granitoid complex are evident. In the west, in the Kireysky anticlinorium, pre-Devonian granodiorites and biotite granites are developed. In the area of the Konsky synclinorium granitoids cut the Lower Devonian series and are overlain by the Middle-Upper Devonian deposits. The difference in age of granitoids of these areas is reflected in different tectonic forms and the varied character of the volcanism.

The interrelation of facies of the upper sec tion of the Lower Devonian series is best exhibited in the Kumkul horst-anticline. Along the Zhaksy-Kon river, the upper section is represented by brownish-red sandstones with grains of various sizes and by rare beds of quartz albitophyres. At a distance of 8 to 10 km east, along the right bank of the Zhaman-Kon river, a large amount of acid tuffs appear in the described section, and effusive rocks are almost absent. Along the strike of the horst-anticline, the thickness of beds of volcanic rocks increases towards the east and they begin to predominate in outcrops. Within the Konsky synclinorium (the basin of the Zhaman-Shad river), exposures of various volcanic rocks of the Albitophyric formation (albitophyres, quartz albitophyres, liparitic porphyries, and tuffs) appear.

The above-described regularity of the Lower-Middle Devonian facies change from west-northwest to east-southeast across the strike of the lower Paleozoic tectonic structures. This is also seen on geologic maps of the Sarysu-Teniz uplift and is characteristic for all of its vast area.

The sharpest changes in thickness occur in the same direction. In general, thicknesses increase in the direction towards the Konsky synclinorium. For example, in the western part of the Kyzemchek horst-anticline, the total thickness of the Lower Devonian series is between 1,700 and 1,900 m, and the thickness of the volcanic Albitophyric formation is 1,000 m. In the same structure along the Sarybulak river, the thicknesses are respectively 3,300 and 2,300 m. In the Kumkul horst-anticline, along the Zhaman-Kon river, the thickness of the lower sandstone is 2,200 m and that of the upper volcanic section is 700 m. East from these points, in central parts of the Kon depression, the thickness of the Lower Devonian series is 5,000 m, and volcanic deposits predominate.

Thus, the accumulated material gives a basis for the formulation of one of the main principles governing the geologic history of the Sarysu-Teniz uplift. Various structural indications, the distribution of facies of sediments (figs. 3 and 4), and the whole process of the development of the area indicate that the position of the main structural elements in this section of the earth's crust in the Lower and Middle Devonian was, in general, inherited from earlier stages of the development. The Kirey anticlinorium and the Kon synclinorium were Caledonian structures of the first order which continuously developed and governed the distribution of volcanic activity in the given area, as well as the distribution of facies and the thicknesses of sediments.

The Kireysky anticlinorium, as noted by Bogdanov [1], is Devonian uplift and the Konsky synclinorium is a downwarp, or depression. In the Lower and Middle Devonian the Kirey structure was a zone of uplifting and denudation. Sandstone-conglomerate facies of the Lower Devonian series were deposited along the eastern slope of the uplift; towards the east, they rapidly wedge out and are replaced by other deposits. During almost all of the Devonian period the Kon depression was characterized by some properties of a geosynclinal mobile zone. Prin-

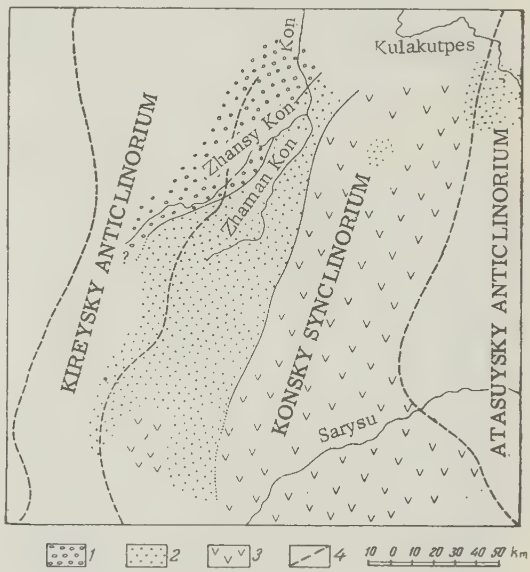

FIGURE 3. The distribution of the Lower-Middle Devonian facies in the center of the Sarysu-Teniz uplift (section D^{a}_{1-2}).

1. the area of predominant occurrence of conglomerates; 2. the area of predominant occurrence of sandstones with some volcanic deposits; 3. the area of predominance of volcanic deposits of intermediate composition, with some conglomerates and sandstones; 4. boundaries between Caledonian structural elements.

cipal centers of Devonian volcanism were situated in this depression, mostly in its central and eastern sections. The Devonian Porphyric formation of the Ural-Tien-Shan folds is typical for this structural zone and characterizes the peculiar tectonic phase and conditions of the formation of rocks.

SUPERIMPOSED DEVONIAN BLOCK-FAULTED STRUCTURES

Regularities in the distribution of facies of the Middle-Upper Devonian Zhaksykon formation over the described territory are not considered in this work, since the problem is complicated and not fully investigated. However, there are many indications that during the formation of the Zhaksykon deposits within the Sarysu-Teniz uplift, under conditions of crustal warping, the formation of mountain structures and volcanic activity, great fractures and block-faulted structures appeared which influenced the distribution of volcanic centers. These fractures often resulted in the appearance of unique tectonic zones and flows of effusive rocks. The framework of fractures still remains obscure in many respects.

One block-faulted structure is situated in the very center of the Sarysu-Teniz uplift and is referred to as the Central Depression. This depression has irregular contours and is somewhat longer in an east-west direction. It divides the Kiresky anticlinorium into two uplifts: the northern and the southern (fig. 5).

Effusions of diabasic and andesitic porphyrites with characteristic amygdaloidal textures are widely distributed within the Central Depression. These rocks are extensively exposed in the basin of the Zhaksy-Kon river and north from the southern uplift. The contours of effusive outcrops distinctly mark the Central Depression on various geologic maps. In the northwestern part of the depression, along the Zhaksy-Kon river, the base of the diabasic mass is exposed. Here it has a thickness of about 1,000 m. It lies on the Middle-Lower Devonian sandstones and is overlain by sediments with fauna and flora of the Frasnian age. It is interesting that this thick mass of basic lavas rapidly wedges out both to the east and west and is replaced in the west by terrigenous sediments and in the east, within the Kon depression, by tuffs.

The clearly exhibited superimposed character of the Central Depression, the very steep and latitudinally extended lower Paleozoic deposits of the Kireysky anticlinorium on the depression's northern and southern margins, and the specific facies of Middle and Upper Devonian basic effusives present a sufficient evidence that the formation of this depression is connected with fractures, which outline its margins and

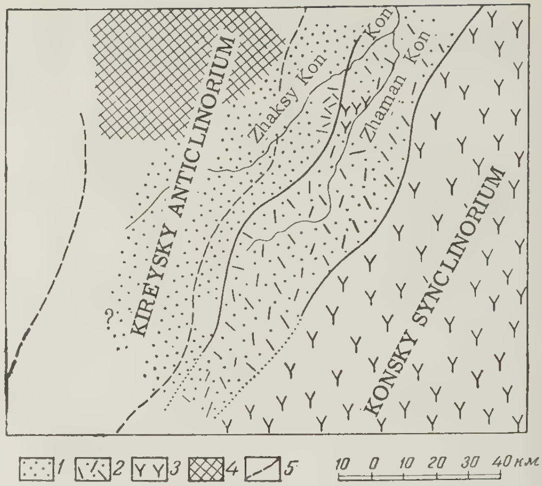

FIGURE 4. The distribution of the Lower-Middle Devonian facies in the center of the Sarysu-Teniz uplift (section D^b_{1-2}).
1. area of the predominant occurrence of sandstones; 2. area of the predominant occurrence of pyroclastic deposits; 3. area of the distribution of volcanic deposits of a mixed composition; 4. area of uplifts and erosion within the northern part of the Kireysky anticlinorium; 5. the boundary between Caledonian structural elements.

dissect linear submeridional Caledonian folds. It can be inferred from the position of basalt flows in the stratigraphic column that the Central Depression appeared in the Middle Devonian. Lower Devonian facies of this area are similar to those of the eastern slope of the Kireysky anticlinorium which were described previously; they do not indicate the existence of a superimposed structure.

A superimposed transverse trough of the Central Depression probably was caused by the existence of upper Paleozoic fault-folds which determined the final Hercynian structure of the Sarysu-Teniz uplift. Later on, the major body of these folds extended through the uplift. Here the deepest graben-synclines are observed; in one of them, lower Carboniferous, middle, and upper Carboniferous deposits are recorded and rocks which are most likely of Permian ages. The hinge of the trough stretches over the Sarysu-Teniz uplift, from the Ulutau anticlinorium in the west, up to the virgation of the Atasuysky and Teturmas anticlinoriums, gradually plunging in an east-southeast direction.

CONCLUSIONS

It was stated above that the sequence of structural forms of the investigated area is exhibited

in three structural stages: the lower, Caledonian or lower Paleozoic; the middle, late Caledonian or Devonian; and the upper, properly Hercynian or Carboniferous. Three cycles in the development of the country correspond to these three structural stages.

The first cycle of development is characterized by complete folding of corresponding deposits, by the formation of the lower Paleozoic basement of the Sarysu-Teniz uplift, and by the completion of the typical geosynclinal stage of the development of the country. The second cycle corresponds to the final stage of the development of the geosyncline, or to the beginning of the orogenic stage, since, at this time, depressions and uplifts replaced linear folded structures (anticlinoriums and synclinoriums). Their geologic columns clearly reveal that areas with rough topography existed at that time [1]. Intense volcanic activity, both effusive and intrusive, was characteristic for this stage.

The major structural elements of Devonian age were inherited from the early Paleozoic. In addition, evidently in Middle Devonian, new tectonic structures, which continued to develop in the Carboniferous appeared. These structures were connected with great fractures in the earth's crust and were superimposed with sharp unconformity on ancient folds. These Hercynian "neoplasms" [minor folds (?)] of the Devonian period originated while the inherited development of the Caledonian structures was still continuing, therefore the Hercynian structures were not determining factors in the geologic history of the country.

During the third cycle, the graben-synclines and horst-anticlines of the Sarysu-Teniz uplift were formed as independent tectonic structures of the first order.

The azimuthal unconformity on the Sarysu-Teniz uplift results from the superimposition of graben-synclines filled with the Upper Devonian and lower Carboniferous calcareous deposits on the more ancient tectonic structures. Since the lower Paleozoic and Devonian folds are characterized by the same structural framework, graben-synclines are discordant in relation to them. The azimuthal unconformity is exhibited by the intersection of the Caledonian and late Caledonian rocks with the Hercynian tectonic forms. However, due to the consequent development of tectonic movements and the gradual stabilization of the structure of the investigated area, this unconformity is differently manifested in the contemporaneous Hercynian structure.

The unconformity between the lower Paleozoic folds and the graben-synclines is exhibited very clearly, because the former have a clear linear orientation. The unconformity between the Devonian structures and graben-synclines is distinctly manifested in places where the Devonian deposits lie directly on top of the lower Paleozoic. Generally, the unconformity is always exhibited more clearly where Lower-Middle Devonian rocks occur. However, in areas of distribution of isometric Devonian

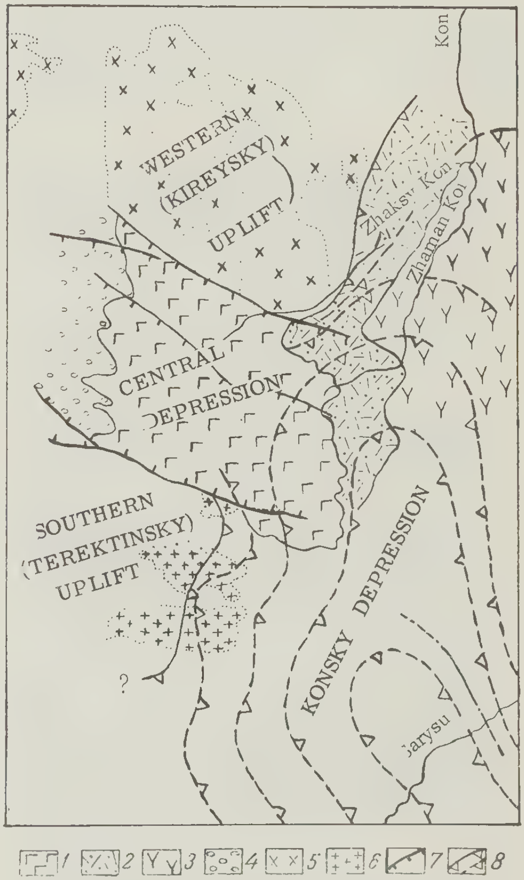

FIGURE 5. Major structural elements in the center of the Sarysu-Teniz uplift at the end of the Middle Devonian.

1. basic effusives in the area of the Central Depression; 2. pyroclastic deposits of the northwestern part of the Konsky Depression; 3. mixed volcanic deposits of the Kon depression; 4. sandstones facies of the western margin of the Central Depression; 5. granitoids of the northern uplift; 6. granitoids in the area of the southern uplift; 7. assumed deformations involving fractures (only in the area of the Central Depression); 8. structural lines.

brachyfolds, which contain effusive rocks, the intersection with younger structures can be almost imperceptible.

In some tectonic zones, red conglomerates and sandstones of the Upper Devonian series correspond to the basal horizon of the marine transgressive beds, formed by the Femennian and lower Carboniferous deposits. Quite naturally, no differences in strike are recorded on the flanks of the graben-synclines. In other areas, the azimuthal unconformity between the Middle-Upper Devonian folds and the graben-synclines is exhibited distinctly enough and is accentuated by the deformations involving fracturing, which are developed on the flanks of the structures.

REFERENCES

1. Bogdanov, A. A., TEKTONIKA ZAPADNOY CHASTI TSENTRALNOGO KAZAKHSTANA [TECTONICS OF THE WESTERN PART OF CENTRAL KAZAKHSTAN]: Sovetskaya Geologiya, 1954, no. 41.

2. Borukavev, R. A., RAZVITIYE TEKTONICHESKIKH STRUKTUR SEVEROVOSTOKA TSENTRALNOGO KAZAKHSTANA [NOTES ON THE EAST-WEST STRUCTURE OF CENTRAL KAZAKHSTAN]: Akademiya Nauk Kaz. SSR Izvestiya, Seriya Geologicheskaya, 1954, v. 18.

3. Volin, A. V., VARISTSYSKAYA SKLADCHATOST V DZHEZKAZGANSKOM RAYONE I YEYE FUNDAMENT [VARIABLE FOLDING IN THE DZHEZKAZGANSK REGION AND ITS FOUNDATION]: Akademiya Nauk SSSR, Izvestiya, Seriya Geologicheskaya, 1947, no. 6.

4. Kassin, N. G., MATERIALY PO PALEOGEOGRAFII KAZAKHSTANA [MATERIAL ON THE PALEOGEOGRAPHY OF KAZAKHSTAN]: Akademiya Nauk Kaz. SSR Izvestiya, 1947.

5. __________, RAZVITIYE GEOLOGICHESKIKH STRUKTUR KAZAKHSTANA [NOTES ON THE GEOLOGIC STRUCTURE OF KAZAKHSTAN]: Izvestiya, Seriya Geologicheskaya, 1951, nos. 14 and 16.

6. Kropotkin, P. N., STROYENIYE SKLADCHATOGO FUNDAMENTA TSENTRALNOGO KAZAKHSTANA [FOUNDATION OF THE FOLDED STRUCTURE OF CENTRAL KAZAKHSTAN]: In-ta geol. nauk, Trudy, Seriya Geologicheskaya, v. 108 (36), 1950.

7. Mazarovich, O. A., K VOPROSU O TEKTONIKE VOSTOCHNOY CHAST I SARYSU-TENGIZSKOGO VODORAZ DELA [NOTES ON THE TECTONIC CHARACTER OF THE SARYSU-TENIZ WATERSHED]: MGU, Vestn., 1956, no. 1.

8. Merkulov, P. L., and A. Ye. Repkina, GEOLOGICHESKAYA KARTA ZAPADNOY CHASTI ARALO-IRTYSHSKOGO VODORAZDELA [GEOLOGIC MAP OF THE WESTERN PART OF THE ARALO-IRTHSHSK WATERSHED]: Mat. po geol. i polezn. iskop. Kazakhstana, Alma-Ata, v. 6, 1938.

9. Nemkov, G. L., K VOPROSU O PERESECHENII KALEDONSKOY SKLADCHATOSTI GERTSINSKOY V TSENTRALNOM KAZAKHSTANE NA PRIMERE STROYENIYA ARGANATINSKOGO ANTIKLINORIYA [ON THE QUESTION OF HERTZIAN (CALEDONIAN) TRANSVERSE FOLDING IN CENTRAL KAZAKHSTAN ON THE PRIMARY STRUCTURE OF THE ARGANATINSK ANTICLINORIUM]: BMOIP, Otd. Geol., v. 28, no. 2, 1953.

10 Peyve, A. F., TIPY I RAZVITIYE PALEOZOYSKIKH STRUKTUR URALO-TYANSHANSKOY GEOSINKLINALNOY OBLASTI [THE TYPE AND CHARACTER OF THE PALEOZOIC STRUCTURE OF THE URAL-TIEN-SHAN GEOSYNCLINAL REGION]: Akademiya Nauk SSSR, Izvestiya, Seriya Geologicheskaya, 1948, no. 6.

11 __________, PRINTSIP UNASLEDOVANNOSTI V TEKTONIKE [INHERITANCE PRINCIPLE IN TECTONICS]: Akademiya Nauk SSSR, Izvestiya, Seriya Geologicheskaya, 1956, no. 6.

12. Peyve, A. V., and V. M. Sinitsyn, NEKOTORYYE OSNOVNYYE VOPROSY UCHENIYA O GEOSINKLINALYAKH [SOME QUESTIONS ON THE CAUSE OF GEOSYNCLINES]: Akademiya Nauk SSSR, Izvestiya, Seriya Geologicheskaya, 1950, no. 4.

13. Shatskiy, N. S., O TEKTONIKE TSENTRALNOGO KAZAKHSTANA [ON THE TECTONICS OF CENTRAL KAZAKHSTAN]: Akademiya Nauk SSSR, Izvestiya, Seriya Geologicheskaya, 1938, nos. 5-6.

14. Khills, Ye., OCHERKI STRUKTURNOY GEOLOGII [NOTES ON STRUCTURAL GEOLOGY]: IIL, Moscow, 1954.

ON THE ORIGIN OF CARBONIC-ACID GAS IN MINERAL WATERS (A CRITICISM AND DISCUSSION OF A. A. SMIRNOV'S VIEWS ON THE NATURE OF CO_2)[1]

by

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• translated by Dean Miller •

ABSTRACT

A. A. Smirnov has proposed in several papers that the formation of CO_2 in ground water is the result of thermodiffusion of atmospheric gases and of gases originating in zones of oxidation in shallow tectonic fractures, rather than as the result of thermometamorphic and biochemical processes. The inadequacy of gaseous thermodiffusion processes, differential seasonal variations in CO_2 content in ground water, and generally biased data are among the basic objections to Smirnov's theory of CO_2 genesis in ground water. --Editor.

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Among numerous problems in the formation of natural gases and subterranean waters, questions on the origin of carbonic acid in the earth's crust have been answered in comparative detail in Soviet and foreign literature during the last decade. The formation, accumulation, and migration of carbonic acid is discussed in papers dealing with the geochemistry of natural gases, the hydrogeology of mineral waters, ore deposition, and contemporary volcanism [1, 2, 6, 12, 13, 17, 18, 19, 20, 21, 24, and others].

As a result of general geologic investigations carried on during the present century, two basic possibilities for the formation of CO_2 in the earth's crust are established: thermometamorphic (in part, strictly magmatic) and biochemical. The chief processes leading to the formation of high concentrations of CO_2 in subterranean waters are augmented by magmatic and thermometamorphic processes arising from the introduction of magma into rock layers.

Biochemical processes, the decay of organic material, plays a lesser role in the formation of CO_2 in the earth's crust. It usually leads to lower concentrations of CO_2 and, as is known, with an admixture of other gases of biochemical origin (CH_3, heavy carbohydrates, and H_2S).

Two articles by A. A. Smirnov [22, 23], in which he expressed new views on the origin of CO_2 in subterranean waters (from air), appeared in Sovetskaya Geologiya (1955, no. 44) and Gidrokhimicheskiye Materialy (1955, v. 24). Categorically denying the accepted idea of the magmatic and thermometamorphic origin of CO_2 in carbonic-acidic ground water, Smirnov stated that "at the base of the formation of this water occurs thermodiffusion of atmospheric gases and gases of the oxidation zone, originating in shallow tectonic fractures intersecting rocks of the folded-mountain areas" [22, p. 98].

Among a number of arguments supporting his views, the author cites the results of experiments carried on by him on the thermodiffusion of gases in closed narrow tubes, data on the variation in CO_2 during winter and summer in several natural (free) carbonic-acid sources. Smirnov considers as an important argument the absence of recent magmatic activity in several regions containing carbonic-acidic water.

An analysis of Smirnov's opinions on the origin in the air of CO_2 in carbonic-acidic water shows that the opinions put forward by him are in complete opposition not only to general geochemical theories on the origin and circulation of CO_2 within the earth's crust, but also to the results of detailed studies and observations of layered carbonic-acidic water made in the Soviet Union for the past decade.

The hypothesis put forward by Smirnov on the air origin of CO_2 in underground water is based on a series of positions deeply in error and contributes nothing to the further study of the geochemistry of natural gases and waters. This demands a more detailed critical examination than was done, with complete correctness, in articles by V. P. Novik-Kachan [14] and A. V. Zhevlakov [5].

The basic objections to the Smirnov hypothesis are the following:

1. Smirnov's ideas on thermodiffusion of gases are untrue at their foundation. To be convinced of this, it is sufficient to turn to the work

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[1] Translated from O proiskhozhdenii uglekislogo gaza mineralnykh vod (po povody vzglyadov A. A. Smirnova na prirodu CO_2): Sovetskaya Geologiya, 1958, no. 1, p. 145-49. The Genesis of CO_2 in Ground Water Containing Carbonic Acid, by Smirnov, appeared in International Geology Review, v. 1, no. 4, April 1959.

[2] The S. Ordzhonikidze Moscow Geological Survey Institute.

of A. I. Brodsky [3] in which Smirnov is referred to. The fact is that the effect of thermodiffusion by itself is very slight. Variations in the concentration of any component of the gaseous mixture at the warm and cold ends of a vertical pipe are insignificant. To increase the effect of thermodiffusion, thermal convection must be increased. But for this it is necessary to warm and cool not the ends of the tube, as Smirnov states, but the opposite sides. The distance between the warm and cold walls must be not more than 1 or 2 centimeters. In other words, the effect of thermodiffusion in fissures in rock to be practically perceptible is impossible, because the walls of these narrow fissures must differ sharply in temperature, which is not possible under natural conditions.

Smirnov attempts to show the possibility of the accumulation of carbonic-acid gas in the lower regions of karst vacuums and open fissures as a result of the thermodiffusion of air by "studying the behavior of a mixture of gases in a system of tubes, using various measurements". Analyzing his own results, Smirnov resorts to an inadmissible extrapolation. He applied data received from a mixture of gases, in which the content of carbonic-acid gas may be as much as 10 percent to air, in which the carbonic-acid gas content is only 0. 03 percent. This is, of course, impossible. Even if at one of the ends of the tube (the cool end, according to Smirnov) the content of carbonic acid gas in the air is 1 percent as a result of thermodiffusion, that variation in concentration of CO_2 constitutes an increase of more than 3,200 percent, an impossible task for thermodiffusion. Forgetting that under stable conditions (without increasing the effect of thermal convection), thermodiffusion is balanced by ordinary diffusion based on the increase in the gradient of concentration, Smirnov erred in thinking that simple thermodiffusion could lead to the deterioration of air and the accumulation of up to 100 percent concentration of carbonic-acid gas at one of the ends of the tube (in fissures under natural conditions).

2. As one of the arguments supporting the air origin of CO_2 in carbonized waters, Smirnov shows that the CO_2 content in solution in summer (higher) and winter (lower) in several natural carbonic-acid sources in the Tien-Shan and the Narzanov valley of the Northern Caucasus varies. It is amazing that the author considers it possible to base his conclusions on scattered data on free-CO_2 sources, whose regimen, as hydrogeologists know well, can undergo significant variations according to season due to changes in the origin and mixing of various waters. At the same time, Smirnov says nothing of the many systematic studies of water regimens, including detailed works on strata-borne carbonated waters (Kislovodsk, Yessentuka, Borzhome, Darasun, Arshan, Karlovaya Vara and many others), which demonstrate the stability of the CO_2 concentration in carbonated waters during the course of the year. So one-sided a use of known data can hardly be accepted in research work.

3. If one agrees with the supposition that CO_2 reaches ground water from the air, then the maximum accumulation of CO_2 in water (with temperature 0° and pressure 1 atmosphere cannot, as is known, exceed 3. 3 grams per liter (g/l). It is quite evident that in migrating farther into rock carbonated waters will lower their concentration of CO_2 through interaction with the rock and mixing with other water.

Meanwhile, there are fully authoritative data at the present time, gathered by various researchers, indicating that in carbonated water in a number of the layers studied, the general CO_2 content (spontaneous and in solution) considerably exceeds the stated upper limit and may be, at Kislovodsk, 4. 8 g/l; at Yamarovka, 6. 5 g/l; at Chvizepse, 7. 2 g/l; at Isti-Su 8. 5 g/l [10, p. 46]. Even more interesting information was obtained from a bore hole in the Yessentuka Kavminvodsk test region. In Mesozoic deposits at a depth of 1, 450 meters (in a trap in the Yessentuka layer of carbonated water), hot carbonated water (up to 50°) with a particularly high CO_2 content was discovered. According to the figures of special studies made by V. N. Kortsenshteyn [11] in 1955 and 1956 with the aid of deep test-boring, the content of CO_2 in water at a depth of 1,000 to 1,400 meters is from 16 g/l of water to 36 g/l. According to data obtained by M. S. Gurevich and I. M. Ovchinnikov in 1956 (at the same test area as the above), the content of CO_2 in many carbonated waters is more than 20 g/l.

The very high CO_2 content in many carbonated waters at depth is also incontestably supported by the extremely ionized structure of the water, and by the presence of calcium and magnesium hydrocarbons which, as is known, are found in solution only with sufficient quantities of free CO_2.

The high CO_2 contents in carbonated water cited above are well known by specialists in mineral-water research, and alone refute the possibility of the formation of carbonated water through the thermodiffusion of CO_2 from the air. To set aside this denial of his views, Smirnov simply ignores known facts and declares that concentrations of CO_2 in underground water greater than 3 to 3. 5 g/l do not exist [23, p. 90, note 7].

In passing, it might be noted that Smirnov, in all of his constructions and measurements, speaks only of CO_2 in solution, and completely ignores spontaneous CO_2 already separated from the the water. The latter must definitely be taken into consideration in defining general gas saturation in water (in cold waters at a depth of 20 to

50 meters we know that all CO_2 is in solution).

In a new article, "On the question of the role of ground waters in the formation, conservation, and dissolution of strata-borne gases of primarily hydrocarbonic, helio-nitrogenic, and carbonic acid structure", (Questions of Hydrogeology and Engineering Geology; Coll. 14, Gosgeoltekhizdat, 1956), Smirnov attempted to show that the average content of free CO_2 in carbonic acidic waters at the moment of their escape to the surface is more than 3. 5 or 3. 6 g/l. Smirnov attempted to explain the formation of spontaneous CO_2 not through its release from solution upon the decrease of subsurface pressure, but through a new formation as a result of the breakdown of bicarbonates. Such an explanation, however, is completely impermissible.

In the first place, in many carbonic-acidic waters--hydrocarbon-sodium (of the Borzhoma type), hydrocarbon-chloride-sodium (Yessentuka type), and also cold weakly-mineralized hydrocarbon-calcium (of the Darasun type)--there is no breakdown of hydrocarbons and no separation of carbonates, even though the content of free CO_2 in these waters is quite large. In the second place, even if we accept Smirnov's hypothesis on the formation of spontaneous CO_2 from the breakdown of hydrocarbons and accept, disregarding actual conditions, that the carbonation by CO_2 in water originates in rock fissures and air and is accompanied by the simultaneous solution of carbonates, even then the maximum possible content in water of free and related CO_2, as an elementary check shows, is entirely insufficient to explain the high content of free CO_2 observed in carbonic-acid springs.

4. Desiring to prove the origin-in-air theory of CO_2 in carbonated waters, Smirnov attempts to deny the wide distribution of CO_2 and its relationship with magmatic and thermometamorphic processes even in areas of contemporary volcanism, such as Kamchatka. In this respect he is cited in the investigations of B. I. Pyp and V. V. Ivanov [22, pp. 89-90; 23, pp. 103-104] in which exactly opposite views are stated. Disregarding the question of an assumption stated in the views of other authors, we may say first of all that in all areas of active volcanism, whether in Kamchatka or the Kuriles, Iceland, Italy, New Zealand, or wherever, CO_2 is the basic, and often almost the sole component, in gas jets formed by high temperature and in gases produced from the numerous high-temperature sources.

In the Kuriles or in the eastern part of the area of active volcanism in Kamchatka, thermal waters are either basically sulfur-carbonic acidic or simply carbonic acidic, and the subterranean origin here (magmatic and thermometamorphic) of CO_2 is not doubted by any investigator familiar with volcanic phenomena. In contrast, nitric alkaline thermal springs are distributed in Kamchatka beyond the zones of active volcanism, but within the limits of the latter only in areas hydrogeologically exposed were carbonated waters noted as being younger, infiltrating water of atmospheric origin. The fragmentary Kamchatkan data cited by Smirnov is regrettably misused and gives a distorted idea of regular observed phenomena.

All sulfur-carbonic and carbonic thermal waters on Kamchatka are not "unsaturated" with CO_2, but, at the moment of escape, release great quantities of CO_2 in the form of free gas, often with considerable boiling and agitation. The high amounts of CO_2 in hot water (up to 75°) which Smirnov adduces, of course, do not reflect the gas saturation capacity of water. For some reason Smirnov ignores this widely-known fact. In sulfuric acid-producing springs closely related to volcanic gases, which occur in craters, calderas, and on the slopes of active volcanoes, CO_2 is thought to be a result of the action of sulfuric acid on carbonate rocks. Because carbonate rocks are not included in Quaternary volcanic deposits, the notion is groundless.

5. Smirnov's statement concerning the absence of a relationship between the distribution of carbonated water regions and recent magmatic activity is completely untrue. Current literature on carbonated water shows conclusively the mutual occurrence of carbonated water and areas of neo-intrusion. In particular, in the U. S. S. R., almost all areas of carbonated water lie within the limits of the territory where young (Tertiary and Quaternary) magmatic activity has occurred. In those isolated cases where recent magmatic activity is not apparent and carbonated waters exist at the surface (for example, in the Tien-Shan), it is completely incorrect to assume that conditions on the surface also exist at great depths, where neo-intrusion might exist. L. G. Greyton [4] also opposed this approach to the study of geologic regularity.

6. It is impossible to bypass Smirnov's statement on the south-to-north migration of carbonated water in the Kislovodsk area. In spite of prospecting data which reveal the most mineralized, the most CO_2 saturated, and the carbonated water under most pressure to the north of the natural locus of its discharge (in a more open structural area), Smirnov contends that "the assumption of the movement of underground water from north to south, from the foothill depression to the mountainous part of the area, is analogous to the assumption that the current of a river can move from its mouth to its headwaters" [22, pp. 92-93]. It is necessary to point out that in this case the author has muddled the conditions of ground water moving without pressure and artesian water under pressure. To deny the possibility of the movement of water under pressure upward along a stratum toward its place of discharge would mean

denying the very bases of hydrogeology.

7. It is also necessary to note that Smirnov's contention that CO_2 is formed only as a result of the thermometamorphosis of limestones is entirely in error. Even at the beginning of this century, in the basic research of R. T. Chamberlin (these experiments are written out in detail in the work of V. V. Beloussov, 1937), it was reported that when any rock, not just a carbonate, is heated to more than 350 or 400°, CO_2 is produced. Thus, the ideas on the air origin of CO_2 in carbonated waters presented in categorical and arbitrary form by Smirnov do not agree with basic geochemical and hydrogeologic principles and much data on the distribution of carbonated waters.

It must be recognized that Smirnov's views, based on random facts, the nonobjective use of many materials, and unsupported by cogent experiments, are thoroughly in error and misdirect young scientists in regard to one of the elementary questions of hydrochemistry, for example, the article by V. M. Stepanov, "Some natural conformities in the distribution of mineral springs in the Transcaucasus", Voprosy Gidrogeologii i Inzhenephoy Geologii, Coll. 14, Gosgeoltekhizdat, 1956. In addition, in order to analyze objectively the accurate data already gathered on strata-borne carbonated water, the author took the dangerous route of expressing original, but undemonstrated, conclusions.

REFERENCES

1. Beloussov, V. V., OCHERKI GEOKHIMII PRIRODNYKH GAZOV [NOTES ON THE GEOCHEMISTRY OF NATURAL GASES]: 1934.

2. Betekhtin, A. G., GIDROTERMALNYYE RASTVORY, IKH PRIRODA I PROTSESSY RUDOOBRAZOVANIYA, V CB. OSNOVNYYE PROBLEMY V UCHENII O MAGMATOGENNYKH RUDNYKH MESTOROZHDENIYAKH [HYDROTHERMAL SOLUTIONS, THEIR NATURE AND THE PROCESSES OF ORE-FORMATION, In: PRINCIPAL PROBLEMS IN THE STUDY OF MAGMATIC ORE LAYERS]: Akademiya Nauk SSSR, 1953.

3. Brodsky, A., FIZICHESKAYA KHIMIYA [PHYSICAL CHEMISTRY]: chap. 2, Goskhimizdat, Moscow, 1949.

4. Creyton, L. G., PRIRODY RUDOOBRAZUYUSHCHEGO FLYUIDA [THE NATURE OF ORE-FORMING FLUIDS]: Gosgeolizdat, Moscow, 1946.

5. Zhevlakov, A. V., K VOPROSU O PRIRODE CO_2 UGLEKISLYKH PODZEMNYKH VOD [ON THE QUESTION OF THE NATURE OF CO_2 IN CARBONATED GROUND WATER]: Sovetskaya Geologiya, 1956, no. 56.

6. Zavaritsky, A. N., and V. I. Reyneke, KAMCHATKA, V CB. PRIRODNYYE GAZY SSSR [KAMCHATKA, In: NATURAL GASES IN THE U. S. S. R.]: ONTI NKTP SSSR, 1935.

7. Ivanov, V. V., GIDROTERMY KAMCHATSKO-KURILSKOY VULKANICHESKOY ZONY [HYDROTHERMAL ANALYSIS OF WATER IN THE KAMCHATKA-KURIL ISLAND VOLCANIC ZONE]: MOIP, Byull., Otd. Geolog., v. 29, no. 5, II, 1954.

8. ______________, O PROISKHOZHDENII KAMCHATSKIKH MINERALNYKH VOD, V. CB. VOPROSY IZUCHENIYA KURORTNYKH RESURSOV SSSR [ON THE ORIGIN OF THE KAMCHATKA MINERAL WATERS, In: QUESTIONS ON THE STUDY OF HEALTH-RESORT RESOURCES IN THE U. S. S. R.]: Medgiz, 1955.

9. ___________, GIDROTERMY OCHAGOV SOVREMENNOGO VULKANIZMA KAMCHATKI I KURILSKIKH OSTROVOV [LOCI OF HYDROTHERMAL ACTIVITY IN PRESENT-DAY KAMCHATKA AND KURIL ISLAND VOLCANISM]: Akademiya Nauk SSSR, Trudy Labor. Vulkanologii, 1956, no. 12.

10. ___________, GIDROGEOLOGIYA GLAVNEYSHIKH TIPOV MINERALNYKH VOD [HYDROGEOLOGY OF THE PRINCIPAL TYPES OF MINERAL WATERS]: Osnovy Kurotologii, Medgiz, 1956, no. 1.

11. Kortsenshteyn, V. N., NOVYYE DANNYYE PO GAZONASYSHCHENNOSTI MEZOZOYSKIKH VODONOSNYKH GORIZONTOV KAVKAZSKIKH MINERALNYKH VOD [NEW DATA ON GAS SATURABILITY OF MESOZOIC WATER-BEARING HORIZONS IN THE CAUCASIAN MINERAL WATERS]: Vses. Neft. in-ta, Trudy, 1957, no. 12.

12. Kozlov, A. L., PROBLEMY GEOKHIMII PRIRODNYKH GAZOV [PROBLEMS IN THE GEOCHEMISTRY OF NATURAL GASES]: Gostekhizdat, 1950.

13. Korzhinsky, D. S., FAKTORY MINERALNYKH RAVNOVESY I MINERALOGICHESKIYE FATSII GLUBINNOSTI [FACTORS IN MINERAL EQUILIBRIUM AND MINERALOGIC FACIES DEPTH]: Akademiya Nauk SSSR, Trudy in-ta Geol. Nauk, Seriya Petrograficheskaya, v. 12, no. 5, 1940.

14. Novik-Kachan, V. P., O PROISKHOZHDENII UGLEKISLOGO GAZA V PODZEMNYKH VODAKH [ON THE ORIGIN OF CARBONIC-ACID GAS IN GROUND WATER]: Sovetskaya Geologiya, 1956, no. 56.

15. Ovchinnikov, A. M., MINERALNYYE VODY

[MINERAL WATERS]: Gosgeolizdat, Moscow, 1947.

16. Ovchinnikov, A. M., OSNOVNYYE PRINTSIPY ZONALNOSTI MINERALNYKH VOD KAVKAZA [BASIC PRINCIPLES IN CAUCASIAN MINERAL WATERS]: MGRI, Trudy, v. 23, 1948.

17. __________, GIDROGEOLOGICHESKY OCHERK RAYONA KAVKAZSKIKH MINERALNYKH VOD [HYDROGEOLOGICAL SKETCH OF THE CAUCASIAN MINERAL-WATER AREA]: Akademiya Nauk SSSR, Cb. pamyati A. D. Arkhangelskogo, 1951.

18. __________, MINERALNYYE VODY KURORTA KARLOVYVARY V CHEKHOSLOVAKII [MINERAL WATERS OF THE KARLOVYVARA SPA IN CZECHOSLOVAKIA]: Zhurnal Vporosy Kurortologii, Fizioterapii i Lechebnoy Fizicheskoy Kultury, 1955, no. 4.

19. __________, ZAKONOMERNOSTI RASROSTRANENIYA I FORMIROVANIYA UGLEKISLYKH GIDROTERM [REGULARITY OF DISTRIBUTION AND FORMATION OF CARBONIC-ACID HYDROTHERMS]: Akademiya Nauk SSSR, Tezisy Dokladov 1-go Vsesoyuznogo soveshchaniya po geotermicheskim issledovaniyam v SSSR, 1956.

20. Pyp, B. I., TERMALNYYE KLYUCHI KAMCHATKI [THERMAL SPRINGS OF KAMCHATKA]: Akademiya Nauk SSSR, Seriya Kamchatskaya, 1937, no. 2.

21. __________, MATERIALY PO GEOLOGII I PETROGRAFII REK AVACHI, ROSSOSHINOY, GAZANKI I NALACHEVY NA KAMCHATKE [MATERIALS ON THE GEOLOGY AND PETROGRAPHY OF THE AVACHA, ROSSOSHINA, GAZANKA, AND NALACHEVA RIVERS OF KAMCHATKA]: Akademiya Nauk SSSR, Trudy Kamchatskoy Kompleksnoy Ekspeditsii 1936-37, SOPS, v. 2, 1941.

22. Smirnov, A. A., O FORMIROVANII UGLEKISLYKH PODZEMNYKH VOD [ON THE FORMATION OF CARBONIC-ACIDIC GROUND WATERS]: Gidrokhimicheskiye Materialy, v. 24, 1955.

23. __________, O PRIRODE CO_2 UGLEKISLYKH PODZEMNYKH VOD [ON THE NATURE OF CO_2 IN CARBONIC-ACID GROUND WATER]: Sovetskaya Geologiya, 1955, no. 14.

24. Tolstikhin, N. I., PROVINTSII MINERALNYKH VOD SSSR [MINERAL-WATER PROVINCES IN THE U. S. S. R.]: Probl. Sov. Geol., 1938, no. 3.

Notes on international scientific meetings

REVIEWS OF SOVIET PAPERS PRESENTED AT THE INTERNATIONAL ASSOCIATION OF SEISMOLOGY AND PHYSICS OF THE EARTH'S INTERIOR

Toronto, September 1957

The Academy of Sciences of the U. S. S. R. has published for its National Committee for Geodesy and Geophysics, short reviews of articles presented by Soviet scientists at the September 1957 meetings of the International Association of Seismology and Physics of the Earth's Interior held in Toronto during the XI General Assembly of the International Union of Geodesy and Geophysics. These reviews are presented as follows:

Beloussov, V. V. ON TYPES AND ORIGIN OF FOLDING. There is no doubt, in the light of modern data, that folding is a secondary phenomenon derived from the vertical oscillations of the earth's crust. The most difficult problem here is the mechanism linking vertical oscillations to folding.

Because data on the structure of the folding zones were not sufficient, special structural investigations have been undertaken. This report is based on the preliminary results of these investigations.

The division of the earth's crust into separate blocks during the process of its vertical oscillations is of essential importance for folding. Folding is a reaction of stratified plastic rocks to the differential vertical oscillations of blocks.

With regard to the relative complexity of this reaction there are three types of folding to be distinguished (on a kinematic basis): block-folding, squeezing-folding and compressional folding.

The block-folding is associated with the most simple and direct reflection of the block movements in stratified rocks.

A further complexity in the folding structure is caused by the appearance and intensification of the elements of the horizontal movement of masses. When the latter takes place in rocks of the most plastic type only, squeezing-folding originates, linked with a flow of the plastic material from one place and its accumulation in another. The following processes take place during this folding: a) the horizontal flow of plastic rocks under the effect of the load of underlying rocks, and b) the squeezing out of light plastic rocks from under heavier rocks, c) the forcing of rocks away from the crests of anticlines.

Compressional folding (morphologically regarded as holomorphic) is related to a horizontal compression of nonhomogeneous and thick formations. The compression may have its causes in: a) a gravitational slipping of the upper part of an elevated block and its pressure on adjacent lower blocks; b) the slipping aside of the upper part of elevated blocks as the result of the forcing of rocks away from the anticline crest; c) a free gravitational sliding down slopes; d) stretching of layers caused probably by the repetition of arching processes and subsidence of another region.

A variety of the causes of the compressional folding have a common basis in the fact that they are all equally related to intensive and contrasting vertical oscillations of the earth's crust which is why compressional foldings of different origin are located in the same zones (geosynclines).

The differing origin of compressional folding forces a geologist to face the necessity of discovering local causes of folding in each folded region. A further study of the folding problem requires special structural investigations in different folding zones and modeling, taking into account in its technique the basic peculiarities of natural folding.

Beloussov, V. V. DEVELOPMENT OF GEOSYNCLINES. A geosyncline is mainly defined as a region of the contrasting development of intensive oscillatory movements of the earth's crust. Within it, zones of intensive subsidence alternate with zones of intensive elevation. Also, a geosyncline is a locus of folding and the considerable development of magmatism. All the phenomena taking place in a geosyncline are mutually associated.

In their development, geosynclines are subordinated to the periodicity of the general oscillations of the earth's crust characteristic of the whole globe. Because of this, there are tectonic cycles and stages in the development of geosynclines.

Each tectonic cycle is divided into two stages: during the first, subsidence is prevalent, during

the second, elevation. A replacement of the dominance of subsidence by that of elevation is termed by the author a general inversion.

The first stage is characterized by initial submarine volcanic activity, initial intrusion and weak preliminary folding; on the borders between subsidence and elevation zones "deep faults" may originate. Sedimentary formations, reflecting subsidence domination, shift from lower terrigenous to calcareous.

Between the two aforementioned stages not only general but "particular" inversions take place. They are expressed in the formation of new elevations inside zones of previous depression. In connection with this a wave-like process is observed in the geosynclines: new "central elevations" expand and grow in opposite directions and overlap the adjoining zones of the previous elevation. This results in a full or partial inversion of elevation and depression inside the geosyncline. As a result of elevation, sedimentary formations change from the upper terrigenous to the lagunary and the molasse.

During the second stage of the cycle an intensive folding develops and gradually migrates from the axes of "central elevations" outside, thus eventually embracing the whole geosyncline though with different intensity in different zones. There are natural relations between the strike, vergency and intensity of folding, on the one hand, and oscillations of the earth's crust, on the other.

During the second stage magmatism actively develops in the following succession: granite batholithes, dykes, extrusions.

The cycle ends in mountain building accompanied by crustal splitting and block displacement.

In post-Archean time geosynclines become more narrow with each cycle at the expense of platform expansion. Between typical geosynclines and platform states there is commonly an intermediate "parageosyncline" state.

The whole complex of geosynclines as well as the location, form and history of geosynclines as a whole testifies that there are no signs of a general horizontal compression of the earth's crust or great horizontal displacement of it. The whole life of geosynclines is determined by differential vertical movements of separate blocks of the earth's crust. Such vertical movements develop either as pure movements or as movements complicated by derivative deformations in the strata. One of these complications is folding.

Balavadze, B. K., and G. K. Tvaltvadze.

STRUCTURE OF THE EARTH'S CRUST IN GEORGIA FROM GEOPHYSICAL EVIDENCE. To study the structure and physical properties of the layers composing the earth's crust in Georgia as well as the adjoining regions of the Caucasus, the Geophysical Institute (now Institute for Earth Physics) of the Academy of Sciences of the U. S. S. R. (academicians G. A. Gamburtzev; E. A. Koridalin) and the Institute of Geophysics of the Georgian SSR (B. K. Balavadze, G. K. Tvaltvadze) have made joint studies of seismometric and gravimetric data.

Seismic investigations have been made in separate intermontane regions in the Caucasus and the Akhalkalaki Nagorie using deep seismic sounding of the earth's crust and by registering elastic waves from powerful industrial blasts.

With the help of gravimeters, gravity observations were conducted all over Georgia. The material was treated using the Bouguer reduction with an account of the corrections due to the influence of topographical masses and the deviation of the geoid from the spheroid.

A densitometric survey of the entire territory explored has also been made.

The results of the seismic investigations aimed at revealing the nature of separate complexes composing the earth's crust in the Kura depression of the Caucasus follows:

a) a sedimentary layer with a thickness from 0 to 8 km and effective and mean velocities of S and P waves respectively: V_p = 3.5 - 4.4 km per sec.; V_s = 2.2 - 2.6 km per sec.;

b) a granite layer divided into two parts: the upper part being from 4 to 8 km thick, with the following velocities:

V_p = 5.6 km per sec.; V_s = 3.4 km per sec. and the lower part being from 8 to 10 km thick, with the velocities:

V_p = 6.0 km per sec.; V_s = 3.4 km per sec.;

c) a basalt layer from 23 to 26 km thick, with the velocities:

V_p = 6.7 km per sec.; V_s = 4.0 km per sec.

Thus, the thickness of the earth's crust in the depressed part of the Caucasus is of the order of 48-50 km.

The boundary velocities in the mantle substratum are:

V_{bp} = 7.9-8.1 km per sec.; V_{bs} = 4.6-4.7 km per sec.

Taking peculiarities in the structure of the earth's crust into account, a diagram of travel-time curves for different focal depths has been drawn up using the following formulae:
for direct waves:

$$t_{kn} = \frac{h - \sum_{1}^{k-1} H_i}{V \sin l_k} + \sum_{1}^{k-1} \frac{H_i}{V_i \sin l_i};$$

for head waves:

$$t_{kn} = \frac{\Delta}{V_n} + \frac{\sum_{1}^{k} H_i - (h - H_k)}{V_k} \sin l_{kn} +$$

$$+ \sum_{1}^{k-1} \frac{H_i}{V_i} \sin l_{in} + \sum_{k+1}^{n-1} \frac{2H_i}{V_i} \sin l_{in}.$$

with the focus under the earth's crust:

$$t_{NN} = \int_0^{h-H} \frac{dz}{V_n^o (1 + \beta z) \sqrt{1 + \beta z)^2 \cos l_n}} +$$

$$\sum_{1}^{N-1} \frac{H_i}{V_i \sin l_i}.$$

Considering the gravity anomaly in the territory of Georgia mostly as the result of an influence of disturbing masses in the sedimentary layer and at the foundations of the granite and basalt layers, an attempt was made to solve the inverse gravimetric problem quantitatively by means of seismic, magnetic, geologic and densitometric data, also utilizing some international data on the structure of the earth's crust from geophysical works.

It is seen that the mean density of sedimentary formations ranges from 1.9 to 2.75, while the densities of the granite, basalt and mantle layers are respectively equal to: 2.65; 2.85 and 3.40 gr. per cm^3.

As a result of a thorough interpretation of the above data, it was found that:

The thickness of the earth's crust in Georgia ranges approximately from 40 to 67 km, where the greatest crust thickness (50-67 km) is supposed to be under the central part of the Great Caucasus and under the Akhalkalaki Nagorie, and the least thickness - (40-45 km) - under the Dzirula crystalline massif and Tsikhisoziri. Under the Kolkhida lowland the thickness of the earth's crust gradually decreases towards the Black Sea.

The approximate range of thickness of layers of the earth's crust in Georgia along the analyzed profiles seems to be the following: for the sedimentary layer - from 0 to 8 km, granite layer - from 14 to 35 km, basalt layer - from 24 to 35 km. It should be noted here that owing to the insufficient differentiation of density on the discontinuities of basalt-granite and granite-sedimentary layers these discontinuities are determined less confidently than those of the substratum-basalt layer (the Mohorovičić surface).

The general character of changes in regional gravity anomalies in Georgia is determined in mountainous regions by a change in, mainly, the substratum surface, which is the place of greatest variation in the density and distribution velocity of elastic waves, and in intermontane and foothill regions chiefly by a change in the surfaces of granite and the substratum.

Bune, V. I. EXPERIENCE IN USING ENERGY CHARACTERISTICS IN THE STUDY OF TADJIKISTAN SEISMICITY. Methods of classifying earthquakes in Tadjikistan by instrumental data measuring their energy are based on the estimates of earthquake energy using the Golytzin method and of the correlation of the energy value with the determinations of M and of maximum distance in registration.

Epicenters of strong earthquakes in Tadjikistan are, mainly, distributed regularly. The zone of strong earthquakes stretches in a nearly latitudinal direction along the border of the Southern Tien-Shan and along the southern spurs of the Gissar and Alai Ridges.

A plot south of the joint of the Gissar, Zeravshan and Alai ridges is especially active. The zone of intensive activity also includes the Peter 1 ridge.

Beyond this, south of the Pamirs border (Darvaza ridge), seismic activity decreases drastically.

A zone of strong deep-focus earthquakes stretches southwest of Murgab to Horog and further to the southwest into the territory of Afghanistan.

The greater part of strong deep-focus earthquakes occur southwest of Horog, in the northern spurs of Hindu Kush.

Zones of the most numerous weak earthquakes which were observed in Tadjikistan within a short period of time mostly coincide with those of strong earthquakes.

A comparative estimate of seismic activity in various regions can be made by determining the seismicity coefficient after Topercher, by constructing graphs of dependence between the frequency and energy of earthquakes after

Gutenberg (seismicity graphs), as well as by drawing up graphs of seismic energy with respect to time.

A comparative analysis of the seismicity of three regions in Tadjikistan (the Hait, Tovil-Dora and Stalinabad regions) and the use of an estimate of earthquake energy enables us to characterize the seismicity of different regions in figures and diagrams.

These data are vivid evidence of the high activity of the Hait region as compared with other regions in Tadjikistan.

The analysis of seismic activity of narrower epicentral zones requires much higher accuracy in determining epicenter coordinates. Such accuracy ($\pm$ 3 km on the average) may be achieved by expeditionary work at temporary stations.

Vvedenskaya, A. V., and L. M. Balakina. SOME PECULIARITIES OF A DISPLACEMENT FIELD OF P AND S WAVES PROPAGATING IN THE EARTH'S MANTLE. The study of the earth's mantle structure by seismic methods is based mainly on data on the propagation velocities of P and S waves at various depths. The values of these seismic-wave velocities are usually determined from travel-time curves.

In this work an attempt was made to utilize observations of P and S displacement amplitudes for studying peculiarities in the structure of the earth's mantle.

The use of dislocation-theory formulae for determining earthquake displacement fields is based on the assumption that a fault exists in the continuous medium of the focus. In this work the Nabarro solution was applied as suggested to describe the displacement fields of Burgers' dislocation.

The results obtained indicate that at epicentral distances of 18^{o} to 20^{o}, 35^{o} to 45^{o}, 52^{o} to 55^{o}, 68^{o} to 71^{o} and about 80^{o} (corresponding to depths of the ray's penetration of 250 to 500 km, 900 to 1,000 km, 1,200 to 1,300 km, 1,900 to 1,950 km and 2,300 km) a noticeable increase of P displacement amplitudes as against SH waves is observed. At the same epicentral distances a displacement increase of SV waves is found with respect to SH waves. These relations are identical in character. The depths mentioned above are meant for the discontinuities in the earth's mantle which were discovered earlier. Using the dislocation theory formulae made it possible to reveal some peculiarities in the propagation of P and S waves in the earth's mantle.

Volarovich, M. P., Z. I. Stakhovskaya, and D. B. Balashov. INVESTIGATION OF ELASTIC PROPERTIES OF ROCKS AT HIGH PRESSURES IN CONNECTION WITH GEOPHYSICAL PROBLEMS.

The mechanical properties of rocks of high pressures have not been much studied until now despite their undoubtedly considerable significance in geophysics and geology. Except for some data in the Manual on Physical Constants for Geologists by Fr. Berch, G. Sherer and G. Spicer, only a few works have been published on this aspect (Birch, Griggs, Handin, Turner, Huges and Jones, Robertson, and others).

In the high-pressure laboratory of the Institute for Earth Physics of the Academy of Sciences of the U. S. S. R., methods of investigation of the elastic properties of rocks at high pressures on all sites have been worked out. Samples of rock sealed in copper shells were placed into thickwalled steel bombs with a gas pressure (N) of as much as 5,000 kg per cm^2.

To measure the velocities of elastic P waves in the rocks, samples were shaped into the form of bars 20 to 30 cm thick and 3 cm in diameter, an impulse ultrasound seismoscope with a cathode-ray oscillograph was used. Electromechanical transformers made of dihydrophosphate of NH_4 (a transmitter and receiver of ultrasound) were placed inside the high-pressure bomb. Young's modulus was measured at high pressures by a statistical method as the plates bent for the first time. A rock sample 21 cm by 5 cm by 5 cm was placed horizontally on two supports inside the high-pressure bomb. A concentrated load in the center of the plate was applied by a piston driven by reduction gears. Measurement of the acting force and deformation (deflections of the plate) was made using elastic elements (dynamometer and deformator) with attached tension indicator.

There is a rapid velocity increase of P waves (by 8 to 15 percent) and Young's modulus (by 30 to 80 percent) in basalt, gabbro, syenite, dolomite, and others as the pressure rises up to 800 or 1200 kg per cm^2. As pressure increases to 5,000 kg per cm^2, the velocity of elastic waves and Young's modulus increase only slightly. This is accounted for by the closing of pores in rock samples at pressures of the order of 1000 kg per cm^2. At pressures greater than that rocks acquire, to a great extent, the properties of a solid, homogeneous elastic substance.

Pressures of 5,000 kg per cm^2 should occur at depths of about 20 km in the earth, where the foci of destructive earthquakes occur. Therefore the results obtained apply in studies of earthquake physics. They can be applied in the interpretation of data from seismic prospecting as well as in developing theories involving the modeling of geotectonic processes.

Volarovich, M. P., and E. I. Parkhomenko. PIEZOELECTRIC EFFECT OF ROCKS. To

elucidate the problem of the relation of electrical phenomena to seismic processes, laboratory studies were performed to reveal the electrifical characteristics of rocks under mechanical stresses. The use of highly sensitive equipment (an ultrasound seismoscope) permitted the discovery of a new property of rocks containing quartz grains: a piezoelectrical effect. The piezoeffect was found in granite, gneiss, quartzite, sandstone, and similar rocks.

The method of investigation consisted in producing exciting elastic oscillations of ultrasonic frequency in a rock sample. By the piezoelectric effect, these vibrations were transformed into an oscillating electric current. Samples of the above rocks, which had been shaped as rectangular parallelopipeds - thus worked as electromechanical transformers, that is, transmitters and receivers of ultrasound.

Following from this discovery of the piezoelectric effect in rocks, theoretical studies for determining possible ideal piezoelectrical quartz textures (after A. V. Shubnikov) were carried out. It was shown that if rock contains quartz of either the right-hand type or left-hand type, but not both, and if the grains are orientated with respect to an electrical or optical axis, textures of symmetry ∞ or $\infty : 2$ may be obtained respectively. If both quartz forms occur in equal quantity, texture of symmetry $\infty \cdot m$ is obtained.

For an ideal texture $\infty \cdot m$ wholly composed of quartz grains, a piezoelectric modulus during a longitudinal effect must be equal to the quartz piezomodulus.

A statistical method of quantitative measurements of piezoelectric modulus with a sensitive electrometer showed that the piezoelectric effect in rock samples with a volume of tens of cubic centimeters is chiefly owing to non-compensated quartz grains. The effect is approximately one hundred times less than in rock with monocrystalline quartz; greater size of the quartz grains in a rock gives a greater piezoelectric modulus. The study of the longitudinal piezoelectrical effect on rock samples of different volumes ranging from 8 to 800 cm^3, however, showed that at volumes greater than 300 cm^3, size of the sample and size of the quartz grains have no influence on the piezoelectric effect.

In samples of granites having a visible slaty cleavage, the greatest piezomodulus was fixed on facets parallel to the slaty cleavage, and the least, or equal to zero, in a direction normal to the linearity. The granites' piezomodulus was found to differ by about 0.1 percent from that of monocrystalline quartz.

The small value of the piezoelectric modulus in some rocks is explained by the presence of a large amount of a piezoelectrically neutral component (i. e., mineral grains revealing no piezoeffect) as well as by an imperfect orientation of the electrical axes of quartz grains.

The piezoelectric effect of rocks is of interest in earthquakes physics; it may also be important in working out new methods of electronic prospecting.

Veytsman, P. S., I. P. Kosminskaya, and Y. V. Riznichenko. NEW EVIDENCE ON THE STRUCTURE OF THE EARTH'S CRUST AND MOUNTAIN ROOTS IN CENTRAL ASIA FROM SEISMIC DEEP SOUNDING DATA. In the U. S. S. R. as well as other countries, seismic observations of elastic waves from industrial blasts were repeatedly used in the continental investigation of the earth's mantle. Experience shows, however, that these methods often fail to provide the necessary accuracy and detail.

In the Geophysical Institute of the Academy of Sciences of the U. S. S. R., now the Institute for Earth Physics, a new more exact and detailed method of crust study has been developed under Academician G. A. Gamburtsev's guidance. This method of Seismic Deep Sounding (SDS) is similar to modern methods of seismic prospecting.

The development of the SDS method dates back to 1938. The main studies of the earth's crust by this method were carried on 1949-50 and later. In the SDS method special, rather small shots are used and correlation principles of tracing seismic waves recorded by many-channel seismic stations are applied.

In the SDS method head-refracted waves are used, for the most part.

In this respect the SDS method is similar to the correlation method of refracted waves (CMRW), developed in the same institute under G. A. Gamburtsev's guidance, and now widely used in industry. The SDS method differs from the CMRW mainly in the lower frequency used (about 10 c. p. s.) and in the use of more sensitive apparatus. The range of shot distance in the SDS method is much greater than in prospecting and reaches hundreds of kilometers.

In the SDS method, observations are made on longitudinal and non-longitudinal profiles as well as on separate profile crossings located in a certain area. In the case of long profiles, observations are usually made on separate continuous segments. The length of these continuous segments, as well as the intervals between them, range from a few kilometers to dozens of kilometers. In addition to linear observation systems providing a "position" wave correlation, point systems with many-channel azimuthal installations, providing "azimuthal"

wave correlation have been used at one point.

The high resolving power of the SDS method enables us to study the depth and shape of the main seismic discontinuities - the surfaces of the granite and basalt layers and the Mohorovičić Discontinuity, and also to investigate deep faults in the earth's crust connected with earthquake origins.

A comparison of crust sections obtained by the SDS method with gravimetric data makes it possible to select regional gravity anomalies owing to granitic and basaltic layer masses and those of the upper part of the mantle. Observation systems used in SDS enable us to determine the values of the boundary velocities of P seismic waves along the main seismic discontinuities and, in some cases, the average vertical velocities in the crust.

In recent years the SDS method has been used in study of the deep structure of the earth's crust in the most seismically active mountain and foothill regions of Central Asia: the Northern and Southern Tien-Shan, the Pamirs and Turkmenia. The work was carried on in combination with geologic investigations and a study of seismicity of the regions.

In the regions of Central Asia studied, a number of irregularities in crust structure have been found. In the transition zone from platform to mountain regions a considerable increase in the thickness of the earth's crust, ranging from 30 to 70 km, was observed. A variety of relationships between the thickness of the granitic and basaltic layers was found. The relief of the surface of the basaltic layers was in most regions considerably more complex than that of the Mohorovičić Discontinuity.

In the Nothern Tien-Shan, mountain ridges correspond to a rise of the basalt layer and an increase in its thickness in comparison with the depressed regions.

The Mohorovičić Discontinuity, sinking somewhat under the mountain ridges, forms the sloping mountain roots of large mountain systems, whereas in the basaltic layer surface relief is repeated to a great extent. The crust thickness varies from 40 to 53 km, that of the granite layer - from 8 to 17 km, that of the basalt layer - from 23 to 45 km. A similar picture of non-concordant main seismic boundaries was also found in the Southern Tien-Shan (Alai) and Western Turkmenia (Kopet-Dag). A concordant location of the basalt-layer surface and that of the Mohorovičić was found in the Northern Pamirs where both surfaces sink down forming mountain roots, in Western Turkmenia (Bolshoi Balkhan Ridge) where both surfaces rise creating the so-called anti-roots under the mountains.

It should be noted that whereas in the Northern Tien-Shan, mountain roots are formed by an increase in the thickness of the basaltic layer, in the Pamirs they are formed by an increase in the thickness of the granitic layer which in that region amounts to 45 km.

The mountain regions of Central Asia are characterized by large negative gravity anomalies, from 200 to 450 milligals (Bouguer reduction).

A joint quantitative analysis of gravity and seismic data shows that gravity anomalies are caused mainly by the shape and depth of the Mohorovičić Discontinuity. However, the shape and depth of the basaltic layer surface is also of great significance. Where non-concordant with the Mohorovičić Discontinuity, this surface seemingly compensates the gravity anomaly. Thus, different gravity anomalies may be observed in regions with an equal thickness of the earth's curst.

Gzovsky, M. V. METHOD OF MODELING IN TECTONOPHYSICS[1]. We consider that tectonophysics is the science of the mechanism of development of tectonic deformation and faults in the earth's crust. The object of investigation is tectonic (geologic). The problems and the methods of its solution are both tectonic (field observations) and physical (laboratory experiments, modeling, theoretical analysis).

The method of modeling of tectonic deformations and faults developing in the earth's crust must be an essential addition to field tectonic investigations. Despite the fact that the modeling method has been used throughout the history of geology, its main concepts require more work.

The results of testing models can be applied in considering natural geological phenomena only if the models meet conditions of similarity. If these conditions are deduced theoretically and model-making materials with prescribed properties are selected, then it is proposed that our equation system should be used here. These equations describe both the development of elastic and plastic deformations and the formation of fractures. Newly devised instruments make it possible to determine the value of all coefficients and models included in the recommended system of equations.

To solve many tectonophysical problems serious consideration should be given not only to deformations and fractures but also to the stress state of models which up to this time have not been investigated.

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[1] The complete paper appeared in International Geology Review, Vol. 1, No. 4, April 1959.

We have begun the study of the stress state of models of geological objects with an optical method. Its application to tectonophysics was complicated by the fact that only elastic optically active model-making materials were known while the necessary plastic materials were not available. We now have plastic optically active materials and special instruments for determining their mechanical and optical properties.

The examples presented show that a model test under controlled conditions makes it possible:

a) to analyze the effect of different factors on crustal folding.

b) to ascertain how tectonic faults are distributed in space and what their succession in time is if a certain crust deformation takes place.

We use models to study by the optical method:

a) the ratio of the velocity gradient of the upper surface on a deformed part of the earth's crust to the magnitude of tangential stresses inside it in the region of earthquake foci;

b) the influence of a type of tectonic deformation and fault magnitude on the shape and volume of an earthquake focus and on the volume of energy emitted from it;

c) change in the character of earthquake foci with time in the course of the development of tectonic faults.

All these data cannot be obtained by the investigations of natural objects only. Even approximate information from the models facilitates the development of geologic criteria of seismicity.

Gorshkov, G. P. ON SEISMIC-INTENSITY REGIONS OF ASIA. The division of Asia into regions according to seismic intensity is intended to simplify the receipt of data from given points on the place and magnitude of expected earthquakes.

This task can be fulfilled only if a joint analysis of seismic and geological materials is made. It is not sufficient to have obtained seismic data only. Extrapolation is possible only when concrete seismo-tectonic relations are determined.

Among the materials of seismic statistics great importance in the solution of the given problem should be attached to maps of isoseists, especially maps of epicenters with those parameters which are available owing to modern seismic observation.

Among the materials of a geologic nature an important role in determining seismic intensity regions is played by geotectonic data.

A map of seismic intensity for the territory of the U. S. S. R was first compiled in 1937. The latest edition of the map was issued in 1957. Experience showed that a map showing seismic intensity can be successfully used in planning of earthquake-proof construction.

The map of seismic intensity for the territory of the Chinese People's Republic was compiled in China in 1956.

At present, attempts may be made to compile similar maps for other Asian countries. To this end, seismologists and geologists concerned with this work should combine their efforts and set up a permanent commission on seismic intensity at the International Association of Seismology and Physics of the Earth's Interior of the International Union of Geodesy and Geophysics.

Davydov, B. I. PHYSICAL PROPERTIES OF SOLID BODIES AT HIGH PRESSURES. Equations on the state of solid bodies for the pressure magnitudes important in geophysics cannot be obtained directly from experiments because the pressures far exceed those obtainable experimentally. At the same time this magnitude of pressure is still far from that in which the chemical composition of matter loses its importance.

Approximate expressions for the free energy of typical crystalline solid bodies (ionic, valence molecular crystals and metals) have been derived from the quantum theory of solid bodies. These expressions enable us to obtain, in the usual manner, an equation on the state as well as a compressibility and a thermal expansion coefficient as functions of pressure and temperature. The constants entering the formulae can be determined from the experimental data relating to low pressures. The resulting equations are valid up to the pressure at which some phase transition occurs.

Theoretical curves for several substances of interest in geophysics (NaCl, MgO, Fe_3O_4, Mg_2, SiO_4, Si, Ge, Fe) agree well with observed data in the range of pressures obtainable in experiment.

Well-known experimental data indicate a considerable increase in the electric conductivity of the earth's mantle with depth. The ionic conductivity should decrease with the increase in pressure. Therefore it may be thought that in the deep layers of the mantle electric conductivity is electronic.

The theory of electronic semi-conductors enables us to find the dependence of electronic conductivity on pressure and temperature. Analogous calculations are also carried out for the coefficient of thermal conductivity.

Theoretical calculations on phase transitions at high pressures, in particular the transition to the metallic phase, present a more complex computation problem. Approximating the methods of the quantum theory of the solid enable us to evaluate pressures at which such transitions occur. In Si the transition into the metallic phase should occur at a pressure of the order of magnitude of 10^6 to 10^7 atm, whereas in MgO the transition takes place only at a pressure of about 10^8 atm.

Keilis-Borok, V. I. INVESTIGATION OF THE EARTHQUAKE MECHANISM (FAULT PLANE SOLUTIONS). A determination of dynamic parameters of earthquake foci (the mechanical character of rupture in the source; the fault-plane orientation; the direction of the movement) was made by a method described in the 1954 Assembly Publications. It is, in principle, similar to the Byerly method and the method of Japanese seismologists (see the report by Byerly at the present symposium). The main feature of the method is the use of S waves (which makes the obtained results single-valued and drastically reduces the number of the necessary observations) and the ratios of displacement amplitudes in different waves.

Here are the main concrete methodical results achieved within recent years:

a) simple methods excluding the influence of discontinuities on the shape of the observed waves have been worked out. By studying the earthquake mechanism, displacements in the "primary" waves are determined (i. e., displacements which would be observed in the so-called "straightened" rays in a homogeneous medium, the focus being the same). Many waves (refracted and reflected at incidence angles exceeding the critical ones, head waves, etc.) differ from the primary by displacement shape, number and the comparative amplitude of extrema, periods, etc. Usual methods do not make it possible to determine even the signs of the primary waves. However, all possible variations of a displacement shape can be presented theoretically in the form of a set of "standard curves" (see the report "The Dynamical Methods of Investigation of the Earth's Internal Structure and Crust" by the same author). By analyzing these curves one can find and take into account a change in the displacement shape in determining the sign of a primary wave. A change in the shapes of S waves in near earthquakes is especially rapid.

b) a graphic method has been worked out which with the help of Wolf's stereographic projection makes it possible to determine the direction of the "straightened" rays (tangential to the seismic rays in the hypocenter) if there are refracting boundaries of any number and shape.

c) additional theoretical grounds are given to the commonly used substitution of the locus for a multipole (as a rule, it is a dipole with a moment). This multipole is defined as an approximate similarity to a volumetric source, in which the forces or initial motions are distributed as in a modeling focus. The substitution of forces or initial motions produces equivalent results. The dislocation theory (according to Love), in the way it was used by Nabarro in Mechanics, is not applicable directly to the modeling of foci. Its correct application yields the same results as the above theory of volumetric sources. Investigations have been made on the models of combined movements (a shift and a break-away; a non-symmetrical shift, etc.).

d) the methods were tested using the example of the earthquake with a surface focus (the White Wolf fault) in Kern County. The focus was studied by geologic observation of the earthquake consequences. Results by interpretation differ from geological ones by not more than 15 or 20 percent.

Determinations have been made of the mechanism of 300 earthquakes in the main seismically active zones of the U. S. S. R and adjoining regions: the Western Pacific (from the Mariana Islands to the Aleutians) the Hindu-Kush, the Pamirs and Tien-Shan, Kopet-Dag and Western Turkmenia, and the Caucasus. Of special interest is the Garm region (on the border of the Pamirs and Tien-Shan), where about 150 weak earthquakes were studied in one small space.

The basic properties of dislocation in the foci of each zone have been found and compared with tectonics in general:

a) In some regions one dislocation strike prevails in foci and it is approximately longitudinal or transverse in regard to the strike of the main structures. In most zones there are two strikes to be distinguished: longitudinal and transverse, the foci with transverse faults usually being more numerous.

b) The dislocations with intensive horizontal components of movement and with a transverse strike and more frequent in foci than in the main structures. In some cases it goes in line with neotectonic data.

c) Vertical movements in the foci of some regions are characterized by the fact that during earthquakes a fault wing facing a tectonic depression is lifted up in the foci. This is concordant with geological and geophysical evidence on movements in surface foci in Japan; vertical movements during earthquakes are directed towards the opposite side from the secular.

The data obtained are of interest in regard to deep tectonics, and its relation with seismicity. It is necessary to investigate the greatest possible number of foci in different tectonic regions. In connection with this, the recent international exchange of methodical results and experimental data is of paramount importance.

Keilis-Borok, V. I. DYNAMIC METHODS OF INVESTIGATION OF THE EARTH'S INTERNAL STRUCTURE AND CRUST. To study the dispersion and magnitude of Rayleigh and Love waves in a multi-strata medium one can leave the cumbersome solution of elasticity theory equations and analyze instead the structure of boundary conditions.

With such an approach the qualitative theory and the methods of computing the dispersion and resonance of the above waves are elaborated when the source is asymmetric (so that the waves of both types are generated simultaneously). The dispersion surface computed for a three-strata model of the earth's crust makes it possible to determine by the dispersion of Rayleigh waves the thickness of the granitic and basaltic layers separately. If the granitic layer is thin, the curve of group velocities may have another minimum at high frequencies, which complicates the structure of the most intensive oscillations.

The shape and direction of surface displacement depends on the ratio of the falling wave length to the thickness of the surface layers (as well as on the elastic properties of the layers). This dependence is the consequence of a complex interference of a number of waves repeatedly reflected in the surface layers.

The interference law can be coded in a zero-one numeration so that the influence of the surface layers on the shape and direction of motions may be computed on electronic instruments at one time. These calculations can be used to characterize the properties of surface layers when the shape and emergence angle of P and S waves of various periods are known.

By using a stereographic projection (Wolf's) one can build a three-dimensional field of isochrones and also isolines of the anomalies in azimuths and the emergence angles of seismic rays when the medium contains boundaries of any number and curvature. By means of these isolines or special stereographic nomograms one can solve the inverse problem - to determine the existence, incline and strike of the boundaries under a seismic station and, less accurately, the ratio of velocities at these boundaries. Azimuths to the epicenter and emergence angles determined by displacement amplitudes gained through customary observations at seismic stations, may serve as initial data.

Under some stations of the Caucasus an inclined boundary is found which seems to be the foot of a sedimentary thickness covering the granitic layer.

A theoretical seismogram (displacement as a time function) for refracted, reflected and head waves in a multi-strata medium can be built rather simply by means of the formula

$$U = \frac{F}{R}\,\Phi\,(t,\ \phi),$$

where A and ϕ depend on wave type, asymmetry of the source and the ratio of elastic constants on the boundaries passed by the wave. They are computed by means of tables of coefficients of the reflection and refraction of plane waves. R depends on the angles of incidence and thickness of layers and indicates the damping caused by a space increase in the wave front. $\Phi\,(t,\ \phi)$ connects the displacement form with that of the initial impulse and is placed in the family of "standard curves" with the parameter ϕ. The same family may be used in any wave type and any number of layers.

By analyzing theoretical seismograms together with the records of nearby earthquakes, it is possible to distinguish by dynamic properties (comparative magnitude and displacement form) waves which are difficult to identify by arrival times (exchange waves, head waves arriving next to the direct ones, etc.). By singling out these waves one can determine more precisely the structure of the earth's crust. For example, in two regions of Central Asia significant deviations in crustal thickness from the average for the whole region have been determined.

Karus, E. V. ABSORPTION OF ELASTIC WAVES IN ROCKS. One of the ways of perfecting methods of interpretation in seismology and seismic prospecting is to use the dynamic properties of elastic-wave propagation. To make a correct interpretation of dynamic peculiarities, it is necessary first to know the parameters characterizing the absorption properties of rocks. The study of these parameters may be of help in determining the physical and mechanical properties of the rocks.

A density decrease in elastic wave energy during its propagation in rocks takes place mainly for three reasons:

1) increase of the wave front surface (divergence)

2) dispersion of energy in non-homogeneous rocks

3) energy absorption by non-ideal elasticity.

There are many theories dealing with the absorption of elastic waves in solid media, but none which would give a comprehensive explanation of the laws of seismic-wave absorption in various rocks. Experimental studies on the absorption properties of rocks may be a decisive factor in forming such a theory.

To study the absorption properties of rocks, the so-called seismoacoustic method has been used. It was elaborated by the author in collaboration with I. P. Pasechnik, following

suggestions by G. A. Gamburtzev and is based on the study of the propagation nature of elastic harmonic oscillations in rocks with frequencies from 50 to 5,000 cycles per second.

Our methods of field observations together with proper treatment permit the determination of the divergence index, decrement and absorption coefficient of stationary oscillations in rocks.

The results of the field determination of parameters mentioned above make it possible to differentiate rocks by their absorption properties. The greatest absorption (value x) for each given frequency of oscillation was observed in sedimentary rocks occurring near the dry surface (sandy loam, sand); the least absorption -- for metamorphic rocks at depths of from 200 to 300 m (for example, aegirine cherts).

The value of the absorption coefficient for some rocks increases with the frequency of vibrations under a law similar to a linear one, i. e. the absorption coefficient is proportional to the frequency. The value of the absorption decrement for the same rock does not depend on the frequency.

A comparison of the values of the absorption decrement x and phase velocities V_ϕ indicate that x is inversely proportionate to V_ϕ .

The experimental results of studying absorption parameters for different rocks confirm, for the most part, conclusions following from the theory of the absorbtion of elastic waves due to an elastic after-action (B. V. Deryagin).

Kondorskaya, N. V. TRAVEL TIMES AND SOME DYNAMIC CHARACTERISTICS OF SEISMIC WAVES. Earthquake seismograms have been studied from various regions of seismic activity, namely in the Far East (southeast Hokkaido and the Kamchatka region), Central Asia, and Turkey, all registered by U. S. S. R. seismic stations.

Investigations were conducted for epicentral distances exceeding 10^{0} at comparatively short intervals. The main seismic elements of the earthquakes studied were determined by methods independent of travel-time curves.

The difference between the travel times of P and S waves observed (O) and determined (G) by the Jeffreys - Bullen travel-time curves has been examined for corresponding depths of foci. The nature of such deviations has been brought out, and regional peculiarities depending on the location of the station have been found.

The travel times noted for tremors in the Far East, Central Asia and the Caucasus proved to be larger than those determined by the Jeffreys - Bullen travel-time curves.

By statistical averaging, deviations from the Jeffreys - Bullen time curves to larger values indicating in the average, 2-3 and 6-8 sec. for P and S waves respectively, have been determined. An allowance for this peculiarity makes more accurate epicenter determinations possible.

The deviations may be partially explained by the difference between the structure of the earth's crust in the regions investigated and the average structure of the earth's crust all over the globe; also the difference between wave velocities may exert influence on the basalt-ultrabasalt boundary as well as on the layers of the earth's mantle.

The dependence of different body wave amplitudes and their relations with the epicentral distance have been determined for earthquakes in the Far East region from observations at U. S. S. R. seismic stations, due allowance being made for the existence of preferable directions in focus emission. The correlation of theoretical and experimental data makes the determination of the location and nature of some boundaries within the earth's mantle more precise.

Lubimova, E. A. THE EARTH'S THERMAL HISTORY AND ITS GEOPHYSICAL CONSEQUENCES. The earth's thermal regime is being studied from its origin to the present time and different hypotheses are being put forward on the concentration of radioactive elements decreasing with time, the earth's age, and on the coefficient of thermal conductivity. As the initial temperature we take that resulting from the earth's formation from the particles in a gaseous-dust protoplanetary cloud in accordance with O. Y. Schmidt's theory. The distribution of radioactive elements is supposed to be uniform during the first 1 or 2 billion years, after which they are believed to become redistributed with different concentrations in the crust, mantle and in an iron or silicate core.

The solution of the equation of thermal conductivity for a sphere is obtained by means of the Green's function. This way differs from the Laplace transformations usually applied by Lowan, Van Orstrand, Comenetz, and Allan. The latter gives a very slow convergent series for temperature, while Green's function is constructed by means of a reflection method which makes it possible to confine the series to one term and get an analytical expression for temperature and heat flow in the form of two items having a simple physical meaning. Calculations of temperature taking account of change in thermal conductivity with depth were carried out by the hydraulic analogy method on Prof. Lukyanov's laboratory hydrointegrator.

The initial temperature, caused by the impact of particles against the surface of the

growing earth and the compression of the interior through the pressure of the growing outer shell, was everywhere much lower than the melting temperature given by Uffen.

The abundance of radioactive elements in the earth as a whole is taken as equal to the average accumulation of such elements in meteorites. This produces a temperature increase up to 4,000°C at depths over 1,000 km during 4 or 5 billion years. The earth's thermal history represented the secular heating of its interior, but not the secular cooling. The same conclusions seem to have been recently made by Jacobs and Allan.

In the earth's temperature field two regions may be noted, namely, the region of heat escape and a central region inside which all the emitted heat is expended in raising the temperature. The generation of heat below the region of heat escape as well as changes in the physical properties of substances there does not influence the heat flow observed near the earth's surface. The depth of the heat escape region is proportional to $\sqrt{kt}$ where k is thermal diffusity and t is time. If the value of k is always constant, namely, $k = 0.01\ cm^2/sec$, this depth does not exceed 1,000 km at the present time. If $k = 0.1\ cm^2/sec$, the region of escape reaches the boundary of the earth's core in 2 billion years after the planet's formation.

The probable increase of effective thermal conductivity owing to a radioactive transfer of energy at great depth does not produce any losses of inner heat, contrary to what has been assumed by Clarck. Our calculations show that the thermal conductivity of the earth's upper layers decreases with temperature rising, forbid considerable losses of inner heat. The variation of molecular conductivity with a temperature and pressure rise is calculated from Pomeranchuk's formula for the thermal conductivity of dielectrics.

Despite a continuous generation of the temperature inside the region of heat escape slowly decreases during the last 2 or 3 billion years, whereas at depths below 700 km heating is going on. Such a situation leads to the outward movement of the inner part of the earth and to the compression of the outer.

If we assume that the outer layer (the earth's crust) was enriched by radioactive elements owing to their reduction in the earth's mantle, the appearance of such a layer should lead to a considerable increase in surface heat flow as against the flow produced by uniformly distributed sources. Surface heat flow has passed its maximum and has been decreasing during the last 2 or 3 billion years. Its present magnitude is concordant with that calculated if the earth's age is 4 to 5 billion years.

The earth as a whole could not melt in the process of radioactive heating because of high core pressures. Total melting is possible for bodies with much less mass than that of the earth; for example, the Moon, while asteroids could melt only in their centers. However, in the upper part of the earth's mantle the temperature is close to the melting point and this zone can be the location of magmatic sources. This zone does not go deeper than 700 km, the hypocenter area of deep-focus earthquakes.

The distribution of the present temperature in the earth's core is concordant with the hypothesis of a solid inner core and a liquid outer core suggested by K. E. Bullen and by Jacobs.

Medvedev, S. V., and B. Z. Petrushevsky. METHODS AND EXPERIENCE IN DIVIDING THE TERRITORY OF THE U. S. S. R. ACCORDING TO SEISMIC INTENSITY. In seismically active regions of the U. S. S. R. measures are being taken by law to construct buildings with greater resistance to earthquakes.

To determine the extent of seismic effect upon buildings, a special map of seismic intensity for the entire territory of the U. S. S. R. is applied. In 1956 this map was revised and improved. The map of seismic intensity shows regions differing in the earthquake intensity expected on the surface. The earthquake force is determined in grades of intensity. A new seismic scale with twelve intensities, parallel to the scales of Mercali-Kankani-Ziberg, Wood-Neimann and to the new Chinese scale, has been worked out by Dr. S. V. Medvedev and was published in 1953.

The map of seismic intensity in the U. S. S. R. has been compiled on the basis of the study of former earthquakes, the geological and geophysical conditions of their occurrence and their manifestations on the earth's surface.

The results of 40 years of earthquake registration at seismic stations have been presented as an "Atlas of U. S. S. R. Seismicity", where earthquakes are divided according to their magnitude in the focus (M), and epicenters are divided according to the accuracy of the determination of their coordinates and focal depth.

Investigations of the geological conditions of earthquake occurrence were aimed at elucidating a relationship between the geological structure of a region and its seismicity, special attention being devoted to revealing large structural complexes and their joints, the so-called seismic seam joints. Tectonic analysis makes it possible to find the extent of relative mobility in the structural complexes. Earthquakes occur mainly in zones where contemporary tectonic movements are the most contrasted. Relatively intensive, vertical displacement of geological

structures causes shear stresses of great magnitude in the earth's crust and leads to the formation of new faults or of displacement along already existing faults, thereby causing earthquakes.

To study present seismic activity, special expeditions were organized including temporary seismic stations with high-sensitivity equipment. Within a short period of time these stations registered a great number of very weak earthquakes, whose locations outlined the zones of contemporary seismic activity.

Studies in engineering seismology were conducted to obtain a qualitative description of seismic oscillations on the earth's surface and to determine the intensity of possible tremors. Instrument records served as a basis for determining the average values in the range of seismic oscillation. Along with the study of seismic activity, the influence of types of soil (and the conditions of occurrence) on earthquake intensity has been investigated.

The map of seismic intensity in the U. S. S. R. has been compiled using the scale 1:5,000,000. Detailed seismic maps were compiled for some large cities.

Magnitsky, V. A. PROPERTIES OF THE EARTH'S MANTLE AND PHYSICAL NATURE OF THE INTERMEDIATE LAYER (LAYER C). According to the data on the velocities of seismic waves the earth's mantle can be divided into three layers: the upper (layer B), intermediate (layer C) and lower (layer D).

The character of change in the ratio of the bulk modulus to the density k/ρ in the layer D as well as the magnitude of the derivative from dk/dp indicates that layer D can be sidered homogeneous in its composition; the same can be said about the layer B, though with less accuracy.

Two main hypotheses were put forward about the nature of layer C;

1) at depths of from 400 to 900 km a change in chemical composition takes place in layer C;

2) the modification of the crystalline lattice in layer C takes place without an essential change in chemical composition.

Experiments made by P. W. Bridgeman regarding polymorphic transitions at high pressures, as well as theoretical considerations, permit us to insist that a simple rebuilding of the lattice can hardly produce the required change of density and other mechanical properties of the layer C.

Also, a simple change in lattice type cannot account for a rapid increase of electric conductivity at corresponding depths. A rapid change in chemical composition also seems rather improbable.

To explain the uncommon properties of the layer C, the author puts forward the hypothesis that in this layer the transition from the ionic type of bond prevailing in layer B to the covalent type takes place. Such a transition is caused by an increased overlapping of the electronic clouds of neighboring atoms during the shortening of interatomic distances (caused by high pressure) which brings into being intensive attractive exchange forces. In its turn this causes density to increase and elastic modulus to grow

A mere substitution of inter-ionic distances for those obtained by covalent radii makes for a density increase of 18 percent which agrees rather well with the Bullen data. The change in k/ρ agrees also well with the value 1.9 (km per sec)^2 and 1. 5 (km per sec)^2 observed from seismic evidence.

Coefficients of the equations of state for the ionic and covalent types of bond were calculated according to B. I. Davydov's method, using experimental values of k/ρ in the layers B and D. The correlation of the curves obtained for energy shows that the hypothesis on the ionic type of bond in layer D contains a contradiction in principle and therefore ought to be rejected. The hypothesis on the valence type of bond is concordant with experimental data, but requires a small increase of the density in layer D as compared with the density in model A obtained by K. E. Bullen.

A rapid increase in electric conductivity in layer C seems to be explained by the transition from the ionic conductivity type to the semiconductor type.

A comparison of experimental data (obtained by P. W. Bridgeman for olivine) with seismic data has shown that the upper part of the mantle may be formed neither of the olivine tested by P. W. Bridgeman, nor of related rocks (dunite, peridotite). The initial parts of such curves coincide but the inclines of the theoretical and experimental curves diverge sharply.

Monakhov, F. I. DEVELOPMENT OF THE MICROSEISMIC METHOD OF TRACING STORMS AT SEA. Numerous studies of microseisms made by scientists of different countries show that there is undoubtedly an interconnection between microseismic and cyclonic activities over the surface of the sea. New methods of determining the locations of microseismic sources are an important contribution to recent investigations. The positive results of these investigations made it possible to begin a more detailed study of the conditions under which microseisms originate.

It should be noted that many problems related to methods of determining the direction of microseisms and the conditions under which they occur have either not been studied at all, or have been studied insufficiently. No little effort is still needed to make the microseismic method of tracing storms at sea practically useful and effective.

This report contains some results on an analysis of microseismic observations conducted in the Soviet Union for the last 5 years. The following problems are touched upon in the report:

1) the accuracy of determining the direction of microseisms by the tri-station method;

2) the development of a method to determine microseismic direction by the phase transition method;

3) the nature of particle motion in microseismic waves and the emission of Rayleigh and Love waves for use in determining the direction of microseisms;

4) synoptic conditions under which microseisms occur;

5) the location of a microseismic source with respect to the cyclone center.

The following conclusions have been arrived at:

1. The tri-station gives the best results if the distance between seismographs is no less than 2.5 or 3 km or more. Even under this condition, however, a strong dissipation is observed in some directions.

2. An increase in accuracy determining microseismic directions as compared with the accuracy of the tri-station method can be effected by making the bases longer. The recording of microseisms should be thus made not with three but with a large number of seismographs.

3. Oscillations of the earth's particles in microseismic waves as observed on Kamchatka and in the Crimea are of rather a complex character. Rayleigh and Love waves are singled out in rather rare cases, and the direction of their arrival at the observation point is far from being correspondent to the microseismic source. Therefore the practical use of a method determining the direction to the microseismic source based on the registration of Rayleigh or Love waves meets some difficulties.

4. Microseisms originate when the cyclone center and its fronts are passing over the sea's surface. The cold front as against the warm one, and the occluded front is a more intensive microseismic source. The strongest front microseisms are linked with the part of the cold front nearest to the cyclone center.

5. Intensity of microseisms grows in line with a fall in pressure in the cyclone center but with a lag of about 8 to 12 hours. Owing to this, microseism sources lag behind the cyclone center by approximately ten times the velocity of the cyclonic movement in km per hour.

Rykunov, L. N. THE STUDY OF A DECREASE OF P-WAVE AMPLITUDES IN THE SHADOW ZONE ON A MODEL. In considering waves with the epicentral distances [$\Delta > 105^{\circ}$] it is necessary to solve the problem of seismic-wave diffraction in the earth's core. From the large number of works on diffraction devoted to the above problem, quantitative results are obtained only by J. G. Scholte, who estimates the velocity of decrease of P-wave amplitudes with a period of 10 sec, for a fixed process and an ideally liquid core.

A comparison of the Scholte results with seismic data shows that the observed P-wave amplitudes decrease more rapidly than the computed ones. To prove that this difference is the result of the difference between the true core and the ideally liquid core, one has to find out how one or another mechanical property of the matter in the core influences P-wave diffraction. This problem was investigated by the seismic modeling method with an ultrasound seismoscope (as the problem cannot be solved by theoretical methods). In an earth model with a mantle made of a paraffin-polyethylen mixture and meeting all the requirements of similarity, different values were taken for density, all-round bulk modulus and rigidity of the core. The velocity of decrease in P-wave amplitudes in the shadow zone was found to be essentially dependent on a change in the rigidity modulus of the core, while the remaining parameters acquired values near to the similarity demands. A quantitative evaluation of this dependence has shown that it can be used for determining the value of core rigidity. The solution of the qualitative side of the problem is that the rigidity modulus of the earth's core is not zero

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Solovyov, S. L. ENERGY AND MAGNITUDE OF EARTHQUAKES. At present earthquake energy is usually thought of as the sum of the energies of its elastic waves.

In most cases, it is probably sufficient to take account of volumetric wave energy only because the energy of surface waves is comparable with the other only for very strong earthquakes. However, the existing formulae for estimating the energies of surface waves (G. Jeffreys, S. I. Kosenko) contradict some empirical facts and need to be checked.

S-wave energy is the main component in earthquake energy. As a rule, it is several times larger than that of P waves, but the exact ratio of these quantities varies from one earthquake to another. The simplest formula for estimating the energy of S waves is the one for a spherical and symmetrical source in an infinite space, which was first used by B. B. Golitzin. It is best applicable to the wave SH (Δ < 200 km). At greater distances ($\Delta > 20^{\circ}$) the Zoeppritz-Wiechert-Gutenberg formula may be used. The functions necessary for its application can be found, for example, by differentiating the travel-time curve. The coincidence of the energy estimates have been shown by the two formulae.

The asymmetry of energy emission is taken into account by means of corresponding formulae.

Since 1953 an earthquake magnitude scale has been used in the U. S. S. R. The type of M-scale applied was based on surface waves. The magnitude of a shallow earthquake is thought of as the magnitude of the velocity field in surface waves. The corresponding calibrating curve ($3^{\circ} < \Delta < 100^{\circ}$) is drawn independently on the basis of the Gutenberg curve. It is shown that the magnitude determined by soil displacement in the surface waves differs little from that determined by the velocity since the surface wave period depends but slightly on earthquake magnitude.

It was observed that for Pacific foci, ground displacements at coastal stations were one-half or one-third less than those at continental stations with the same epicentral distances.

A study was made on the relationship between energy and magnitude; the work was done separately on weak and strong earthquakes in the Far East and Central Asia. The fact established in the paragraph immediately above leads to a variation between corresponding equations for various regions. A mean equation for Central Asia ($\lg E \approx 11.5 + 1.5M$) coincides approximately with the results of Gutenberg and Richter for California.

It follows from these equations that with the growth of total earthquake energy the relative share of surface wave energy increases.

Investigations have been made on the earthquake energy problem in some of the seismically active regions of the U. S. S. R

Savarensky, E. F. RESULTS OF SEISMIC INVESTIGATIONS IN THE U. S. S. R. The results of the work performed by seismologists of the Academy of Sciences of the U. S. S. R. and the academies of sciences of the Union republics have been collected in a Seismicity Atlas of the U. S. S. R. It is based on conclusions from observations made by U. S. S. R. seismic stations during more than forty years.

An essentially new element of maps in this Atlas as against former ones is a uniform principle of dividing earthquakes by their magnitude, and the accuracy of determining epicenters.

The object of the work is to compile uniform material necessary in solving the following basic problems:

1) study of the causes and conditions of earthquake occurrence;

2) checking the map of seismic intensity in the U. S. S. R.

One of the efficient methods in studying the causes and conditions of earthquake occurrence and elucidating the causes of tectonic processes is the correlation of the locations of geological and geomorphological elements and epicenters, taking into account earthquake magnutide. One more important factor here is the analysis of the territorial distribution of earthquake magnitudes which enables us to evaluate the field of potential energy of tectonic stresses.

The value of the Atlas in the scheme of U. S. S. R. seismic regions is that a knowledge of the magnitude and relative energy of earthquakes as well as of the focal depth makes it possible to estimate objectively energy flux relative to the surface of a medium possessing the mechanical properties of the earth's crust. Such a division into intensity regions, provided that proper corrections for geological and local ground conditions are made, will be more reliable than the former.

There are five main earthquake intensity groups.

Single, extremely strong (catastrophic under Soviet conditions) earthquakes ($M > 7\ 1/2$) are assigned to the first group.

The second group comprises earthquakes which have caused or may cause serious destruction to a large area ($7\ 1/2 > M > 6\ 1/2$). If the focus is in the earth's crust, earthquake intensity reaches 8-9 grades.

The third group comprises earthquakes which have caused or can cause destruction and damage to buildings ($6\ 1/2 > M > 5\ 1/4$). With the focus being in the earth's crust their intensity reaches about 7 grades.

These earthquake groups are of practical value. Deep-focus earthquakes of the same magnitude may not be always accompanied by destruction.

The remaining two group, fourth and fifth, include as a rule, non-destructive earthquakes ($5\ 1/4 > M > 4\ 1/4$, $M > 4$).

The distribution of earthquakes into these two groups was made with allowance for the maximum distance in recording earthquakes. Data on weak earthquakes enable us to establish genetic relations between strong and weak earthquakes, in particular, to determine the dependence between earthquake frequency and magnitude.

Epicenters were classified according to the accuracy of their determination. The first accuracy class (A) comprised epicenters with a possible error in determining the locations of not more than 25 km, which was possible if observations were made by stations next to the epicenters. The second class (B) admitted an error of less than 50 km. If the error was not determined the epicenters were considered to be nonclassifiable.

In focal depth, earthquakes are divided into those within the crust and those under the crust. The latter require the indication of a focal depth.

The basic materials for the Atlas were catalogues and maps of seismicity zones (compiled from the catalogues): 1 - Carpathian Mts, 2 - Crimea, 3 - Caucasus, 4 - Kopet-Dag, 5 - Altai, 6 - Lake Baikal, 7 - Far East, 8 - Arctic.

They include about 10,000 epicenters. A general seismicity map of the U. S. S. R. has also been compiled.

It must be noted that there is irregularity in presenting seismicity in time. This refers mostly to weak earthquakes. A noted gradual increase in their frequency is accounted for both by an actual increase in their number and by an increase in sensitivity of instruments at seismic stations. This was especially evident during the last five-year period, when the stations grew in number and were re-equipped.

Investigations have shown that equal seismicity data for U. S. S. R. territory can be obtained only by the use of earthquake epicenters with $M > 5$.

During recent years permanent and temporary seismic stations of high accuracy and equipped with very sensitive instruments have been at work to find the causes of destructive tremors in the pleistoseist regions of the strongest earthquakes.

These data served as raw material for compiling additional, more detailed maps of such regions. Maps were compiled for the Akhalkalakskoye Nagorie, Shemakha region, Ashkhabad region, Northern Tien-Shan region, and Garm region.

Fyodorov, E. P. RESEARCHES ON NUTATION IN CONNECTION WITH SOME PROBLEMS OF THE EARTH'S CONSTITUTION. In the classical theory of nutation, the earth is assumed to be an absolutely rigid body. It was shown that the earth's elasticity would produce the lengthening of the period of free nutation and a reduction of the coefficients of the so-called Oppolzer's terms in forced latitude variations. Those are the only effects of elastic deformation on the earth's rotation.

The fluidity of the earth's core has been suggested to be capable of producing: a reduction of the constant of the nutation, a change of the form of the nutational ellipse, a lag in the nutation, an augmentation of the coefficients of Oppolzer's terms, and a lag in the forced latitude variations.

The object of this investigation is to see if these effects are revealed by observations.

For this purpose we have availed ourselves of the most extensive and homogeneous series of latitude observations. The results obtained from 135,000 observations at Carloforte, Mizusawa and Ukiah from 1900 to 1934 are as follows:

A) The constant of the nutation is $9'', 198 \pm 0'', 002$, while the theoretical value is near to $9'', 230$. Taking into consideration the amount of observational data used in our computation and the mean error of the result, it may be concluded that the usually adopted value $9'', 210$ needs some negative correction and that a discrepancy between the theoretical and observed values is even greater than was hitherto considered.

B) The ratio of the axes of the nutational ellipse needs no correction.

C) The lag was found in the nutation in longitude only; it is $3', 8 \pm 1', 2$.

A total of about 230,000 observations at Pulkovo, Washington, Carloforte, Mizusawa and Ukiah was used to obtain the lunar diurnal term in the forced latitude variations. Its expression as derived from these data is:

$$\Delta\phi = -\underset{\pm 1}{0''.009} \sin (S - 2☾ + \underset{\pm 4}{15^{o}})$$

$$+ \underset{\pm 1}{0''.002} \sin (S + 2☾).$$

The theoretical expression as derived, taking into account the elastic deformation of the earth is:

$$\Delta\phi = -0''.005 \sin (S - 2☾),$$

where S is local sidereal time and ☾ the mean longitude of the moon.

Schmidt, O. Y. and B. Y. Levin. ORIGIN AND COMPOSITION OF THE EARTH. All investigations of the chemical composition of the entire earth (Chirvinsky, Clarck, Link, Washington, Niggli, Zaslavsky, Fersman) are more or less explicitly based on a conception of its origin, evolution and present internal structure. Besides, they widely utilize data on the chemical composition of meteorites which is not always founded on properly adjusted hypotheses on the origin of the earth and of meteorites.

Modern cosmogenic hypotheses by different authors consider that the planets were formed from a cold gas-dust cloud. But while accepting the identical initial state of a planetary substance, these hypotheses differ widely from each other in explanations of the formation of planets themselves.

Kuiper's conception of the formation of planets from massive gas-dust protoplanets leads to an originally incandescent state of the earth, the chemical composition of which was determined by the dissipation of the protoearth's substance. However, as was proved by Urey, an analysis of chemical evidence contradicts this point of view.

The analysis of astronomical and chemical data by O. Schmidt and his collaborators led to the development of a theory according to which the earth was formed from a dusty component of the protoplanetary cloud through the gradual growth of an originally small embryo. According to this theory, the earth was originally cold and its chemical composition was conditioned by the accumulation of various components present in the protoplanetary cloud.

By an analysis of chemical evidence, Urey has shown that the earth's formation was begun with the accumulation of cold solid particles, which accords with the conceptions developed in O. Schmidt's theory.

Meteorites are samples of the nonvolatile part of the protoplanetary cloud substance. The nonvolatile substances served to form the earth (without hydrosphere and atmosphere) and other planets of the earth's group. Therefore data on the composition of meteorites along with geophysical and geochemical data serve as a basis for studying the chemical composition of the earth itself.

The use of the data on meteorite composition faces the following main difficulties:

1) our ideas on the average composition of meteorites are distorted by the destruction and evaporation of meteoric bodies during their flight through the atmosphere.

2) as was recently proved by A. A. Yavnel, meteorites now falling on the earth's surface appear to be the disintegration product of five asteroids (or five asteroid groups) different mainly in iron content. Thus, even the true average composition of meteorites now falling can differ somewhat from the earth's average composition.

Meteorites enable us to find the average composition of the stony and metallic part of the substance but cannot help in determining their relative proportion in the earth. In 1955 the metallic part of the earth's composition was found to be 1/7. According to the latest hypothesis by K. E. Bullen, a gravitational differentiation has taken place in the earth's core which resulted in the formation of an inner core composed of nickel iron. In this case the metallic part of the earth should be about 8 percent. Based on K. E. Bullen's hypotheses and some new analyses of meteorites, a new table of the chemical composition of the earth has been calculated. A comparison of the composition of the earth and its crust permits us to reveal the elements which have been concentrated in the crust during the process of its formation and those which have remained in the mantle.

Shebalin, N. Y. CORRELATION BETWEEN MAGNITUDE AND INTENSITY OF EARTHQUAKES AND THE ASTHENOSPHERE. The influence of discontinuities on the part of the total flow of seismic energy emitted vertically out of the earthquake focus is not significant. In particular, if the focus is under or over a certain discontinuity, the intensity in the epicenter should remain practically invariable. If it is accompanied by a drastic change in the relative amplitudes of surface waves, the latter can be revealed by correlating the earthquake's magnitude and intensity.

Data on magnitude M, intensity 1 and focal depth h were obtained for 225 earthquakes with focal depths from 3 or 5 km to 640 km, magnitude - from 3. 3 to 8. 3, and intensity - from 3 to 11 or 12 grades. Magnitude was determined by the surface-wave method. In determining M for deep-focus earthquakes, the observed amplitudes of the irregular surface wave characteristic of deep-focus earthquakes were used. Corrections for focal depth were not used. The focal depth was determined by the phases pP and sS. The focal depths within the earth's crust were determined by the phase sP.

As a result of interpreting the observations, the following equation linking intensity N and magnitude M has been obtained:

$$1.5\,M - 1 = \delta\,(h),$$

where δ (h) is a parameter depending on a focal depth.

With an increase in the focal depth from 5 km to 80 km or 100 km the value δ (h) changes from minus 1 to plus 4 which means that intensity decreases with the focal depth much more rapidly than the amplitudes of surface waves. For these depths we get:

$$\delta (h) = -3.0 + 3.5 \lg h$$
$$\text{and } I = 1.5 M - 3.5 \lg h + 3.0$$

With a further increase of the focal depth the value δ (h) drastically decreases by approximately 2.5 units after which it goes up again; for depths from 80 or 100 km to 640 km it is expressed by the following equation:

$$I = 1.5 M - 3.4 \lg h + 5.4$$

A rapid increase of δ (h) can be explained only by an essential reduction of surface-wave amplitudes during the passage of the focus through a certain discontinuity.

The same effect should be produced by a layer with a lower velocity (asthenosphere) so far as a part of the energy flow, forming surface waves in a vast zone around the epicenter, goes from below towards the upper boundary of the asthenosphere at overlimited angles and must be screened. Therefore, there are grounds for identifying the boundary of a rapid decrease of (h) and the upper boundary of the asthenosphere. The following data have been obtained on the depth of this boundary: Kamchatka and Japan - about 80 km, Pamirs and Hindu-Kush - about 80 km, the South American Andes - about 65 km, the Caucasus - about 55 km, the Carpathian Mts.-about 100 km, the Aegean Sea and Crete - about 90 km.

The criterion of a constant change of intensity during the passage from the focus through the discontinuity permits us to conclude from the correlation of intensity and magnitude determined by body waves, that the curves f (Δ, h) by B. Gutenberg serving to find magnitude M of deep-focus earthquakes by body waves contain a regular error of the order of 0.7 beginning from the depth of about 80 km.

The U.S. Board on Geographic Names recommends the following usage of certain names in this section:

for	read
Akhalkalaki Nagorie	Akhalkalaksokye Plato
Tadjikistan	Tadzhikistan
Zeravshan ridge	Zeravshanskiy Khrebet
Alai ridge	Alayskiy Khrebet
Darvaza ridge	Darvazskiy Khrebet

-- Editor.

Review Section

Current Digest of the Soviet Press, DIAMOND DEPOSITS IN YAKUTIA AWAIT DEVELOPMENT. A condensation and translation of an article by K. Kondakov and G. Naumov in Voprosy ekonomiki, no. 6, pp. 135-140. Reprinted with permission of copyright holder, Current Digest of the Soviet Press, v. 9, no. 37, published at Columbia University by the Joint Committee on Slavic Studies, New York.

The results of prospecting work carried out by expeditions of the U. S. S. R. Ministry of Geology and Conservation of Mineral Resources has shown that there are tremendous deposits of diamonds in Western Yakutia. One can distinguish six diamond areas in Western Yakutia: the Malaya Botuobuya, the Daldyn-Alakit, the Middle Markha, the Tyung, the Muna and the Northern Olenek.

The most highly prospected deposits at the present time are, in the south, the deposit in the Malaya Botuobuya region, where the famous Mir pipe and the placers in the Ierelyakh River Valley are, and, in the north, the Daldyn-Alakit area, where the Udachnaya pipe is. These deposits are notable for the high diamond content of the rock. The Mir and Udachnaya pipes are not inferior in diamond content to the famous Premier, Jagersfontein and other African deposits.

In these two areas alone the deposits of diamonds are reckoned in millions of carats. They can fully satisfy the demands for industrial diamonds in the near future. The amounts of geological diamond deposits in the Yakut Republic are so great that a very large-scale diamond-mining industry can be assured a steady supply of raw materials.

The size of the Yakut diamonds varies a great deal: from tiny grains to large crystals of three to five or, sometimes, from ten to 11 carats. In the Ierelyakh River region 32.5 carat diamonds have been found. The overwhelming majority of Yakut diamonds are colorless and transparent (of the first water). Under ultraviolet light they glow with a blue or greenish-yellow light. The specific gravity of Yakut diamonds varies from 3.52 to 3.56. The most common foreign bodies are olivine, pyrope and graphite crystals.

We do not yet have complete information for describing Yakut diamonds. Their full description can only be obtained after complete laboratory and industrial tests have been made.

The percentage of gem diamonds in the Yakutia deposits is greater than in the deposits in the Belgian Congo, where the percentage of gem diamonds does not exceed 2%. ...

An evaluation of the economic, physical and geological position of the various areas of distribution of the Yakut diamonds permits us to come to a conclusion about the advisability of putting the Malaya Botuobuya area at the head of the list of those that are to be developed industrially. This is confirmed by the following factors: (1) the quantity of diamonds in the deposits and their proportion in the rock discovered through industrial prospecting makes possible the founding of a large, fully paying diamond-mining enterprise here, which may be worked for a long period; (2) the area's favorable geographical position, not far from the navigable section of the Lena River, will permit the rapid construction of an all-year highway; (3) the existence of the enormous Ust-Markha brown coal deposit, notable for its high energy qualities, at only 270 km from the Mir pipe. Here it will be possible to establish a dependable power supply for a Malaya Botuobuya industrial complex; (4) there are building materials and lumber in the area, and it is near populated points on the Lena and the Vilyui.

The Daldyn-Alakit area, in which the Udachnaya pipe is being studied, also has important diamond deposits, which will permit the foundation of a large enterprise with better labor-productivity rates and cost rates than in the Malaya Botuobuya area. However, the position of this area beyond the Arctic Circle and the fact that it is more than 1000 km. from river ports make for difficulties in setting up an enterprise there, since much time would be necessary for the construction of branch lines and power-generating facilities, the shipment of industrial equipment and the organization of food supply. For these reasons the development of the Daldyn-Alakit area should be undertaken second.

The Middle Markha area is one of placer-diamond deposits. Its economic, physical and geographic conditions are most favorable. The Markha River is navigable at this point, there are deposits of fuel coal, and there are agricultural areas at a distance of 120 km. Besides this a major district center of the Yakut Republic - the village of Nyurba - is not far away.

The nature of the placers in the Markha River Valley permits mining and dressing of the sands with the use of dredges. Despite these favorable conditions, however, the construction of an independent enterprise would not be fully effective because of the smaller amounts of diamonds and the comparatively low proportion of them in the rock. The best plan would be to work these placers with dredges after a power line and a highway have been built to the Daldyn diamond deposits through the Middle Markha area.

There is not enough information for a description of the remaining three areas - the Tyung, the Muna and the Northern Olenek. It is possible to organize approaches to these regions from the Lena, from the direction of Zhigansk and from the north of it. Approaches to the Northern Olenek region can also be organized from the Laptev Sea along the Olenek River.

Therefore the diamond-mining industry must be developed first in the Malaya Botuobuya area and then in the Daldyn-Alakit area. As the prospects for the development of the neighboring Muna area improve, it will be possible to organize the joint exploitation of these areas, which will be considerably more effective than separate development. ...

The main communication routes in the Yakut Republic, including those in Western Yakutia, are the large rivers - the Lena, the Olenek and others. The Taishet-Lena railroad line leads to the rivers of the Lena Basin. There, at the Osetrovo wharves, freight is transferred from the railroad to river boats. The river boats go first down the Lena and then up its tributaries. Part of the freight for the upper and middle Lena Basin goes via the Northern Sea Route through the port of Tiksi.

Freight for the mouths of the other major Yakut rivers is delivered via the sea route and is then shipped up these rivers. Freight addressed to points in the interior of Yakutia not reachable by water will be delivered by trucks, for which long-distance winter highways will be built.

Solution of the transportation problem in the diamond areas of Western Yakutia is especially complex and difficult. A trail has already been surveyed for the Malaya Botuobuya Area, which enjoys the most favorable conditions, and in 1957 construction of a real year-round highway was begun. This will make an uninterrupted flow of supplies to the enterprises possible. This road has so far been planned to go up only to the Mirny settlement, which means, of course, that it can establish full communications neither with all the diamond regions nor with the interior regions of this broad territory, which is rich in natural resources.

In the interests of founding a single industrial center in Western Yakutia, it is necessary to extend the highway from Mukhtuya or Turukty - another point on the Lena - to the navigable part of the Vilyui, approximately in the area of Suntar. The problems of the development of the northern deposits require, first of all, that a winter highway be constructed from the lower Lena, from the Zhigansk area along the watershed of the Muna and Tyung Rivers.

The northern part of the Yakut diamond area in the basin of the Olenek may be developed initially through an improvement in the navigability of this river from its mouth to the settlement of Sukhan. If large diamond deposits are discovered there in the future, it would be advisable to extend a highway into this area from the Zhigansk-Daldyn highway.

One of the important measures for the development of transport routes in Western Yakutia is the improvement of the navigability of the Vilyui, Markha, Muna, Tyung and Olenek Rivers.

Present-day diamond-mining enterprises consume a comparatively large amount of power. ...

Power for the gold, tin, mica and other mining industries in the south and east of the Yakut Republic has been supplied through the construction of many small power stations with mobile engines that burn local wood or liquid fuel transported over long distances.

The diamond-mining industry that is to be founded during the years of the Sixth and Seventh Five-Year Plans in several areas of Western Yakutia must at the same time have a firm electric power base. The construction of one comparatively large power station in the Nyurba area, to be suppled by the rich and easily mined Ust-Markha coal, will unite all the diamond-mining enterprises into one mighty center. Such a power station could also produce power for the state and collective farms of Myurba District, and thus make possible the mechanical irrigation of potato, vegetable and feed crops and provide water for livestock. This in turn would provide the industrial workers with potatoes, vegetables and livestock products. The capacity of this power station should be 40, 000 to 50, 000 kw. The estimated cost of electric power to consumers in the area of the Mir pipe will be about 30 kopeks per kilowatt hour, and in the area of the Udachnaya pipe about 40 kopeks per kilowatt hour. These rates are very favorable in comparison with the rates of some

of the small power stations in the south and and east of Yakutia, where the cost of one kilowatt hour of electricity is sometimes as high as two rubles. ...

Various Yakut diamond regions contain a raw-material supply for the organization of the production of certain types of mineral building materials, as well as timber supplies for construction of wooden installations and the production of building accessories. In the Malaya Botuobuya area there are limestone, sand, gravel and pebbles and, in smaller quantities, clay for bricks. Timber may be cut there for the construction of industrial and public buildings. Comparatively close to Mirny, in the area of the Upper Meik and on the Vilyui, there is gypsum and a great deal of basaltic rock. In the area of the village of Nyurba and the Ust-Markha coal deposits there are sufficient deposits of brick clay to justify the construction of a brickyard. There is also enough rock to supply a slag-rock factory. In this same area there are sand, gravel, and pebbles. There is very little timber here for the production of useful lumber. It will be necessary to ship cement into all areas of Western Yakutia from Eastern Siberia until a cement plant is built in Yakutia.

The situation in the remaining diamond-bearing areas beyond the Artic Circle is considerably worse. There only filler-stone and limestone are present in sufficient quantities. There is neither clay nor construction timber. ...

The builders of the diamond-mining enterprises deal with two quite important problems: first, the organization of the supply of water to the enterprises for industrial and everyday needs, and second, the necessity for overcoming the effects of permafrost on building construction and on diamond mining. In both the Malaya Botuobuya and the Daldyn-Alakit areas the surface water is far from sufficient. It is necessary to carry out searches for underground, inter-permafrost and sub-permafrost water and also to organize hydraulic installations for catching flood waters of the small rivers.

... In order to gain a deeper understanding of the need for the foundation of a large domestic diamond industry it is necessary to consider foreign experience. For example, 70 industrial firms in the U. S. A. use about two-thirds of the world's diamond output. The Industrial Diamond Review for July 1955, contains information about the use of industrial diamonds in U. S. industry taken from a report that the Industrial Diamond Association of America presented to the U. S. government. According to these figures, 60% to 70% of all industrial diamonds, including the lowest qualities imported from the Belgian Congo, are used in the U. S. A. for grinding and milling of precision cutting tools made from hard alloys. About 80% of the impure industrial diamonds in the U. S. A. are crushed for use on grinding wheels. ...

The foreign press discloses that the need for new equipment for producing objects with complex surfaces has increased the demand for new tool designs that make use of diamonds. According to the Maurice Dessau Company (U. S. A.), one new area in which the need for such tools is felt is the manufacture of germanium crystals for triodes in semiconductors. Diamond tools will play an important part in building precision production lines for making machine parts. The wearing qualities of diamond tools are hundreds of times higher than the wearing qualities of hard-alloy tools and can assure that automatic production lines operate for long periods without replacements.

Such are the highly important fields in which it is possible to use industrial diamonds, and such are the advantages of their use in various fields of industry. What, then, will be the demands for industrial diamonds in the U. S. S. R. in the near future, and what should be the volume of diamond production in the years of the present five-year plan ?

Because there is a shortage of domestic diamonds, the use of diamonds in our industry lags behind the demands of modern technological progress. Until diamond deposits were discovered in the western areas of Yakutia, a considerable shortage of diamonds was constantly felt in the Soviet Union. Before the second world war the consumption of industrial diamonds was equal to the 1926 consumption in the U. S. A., and imports into the U. S. S. R. between 1929 and 1936 averaged 23,100 metric carats annually. During the second world war the imports and consumption of diamonds increased considerably.

Our country was cut off from the capitalist diamond markets and was obliged to look for diamond substitutes. Because a rich supply of domestic diamond raw materials has now been discovered, socialist industry must be given the task of introducing advanced types of diamond tools rapidly into production. New machine-tool methods and new technological processes must be worked out in the enterprises and laboratories. These must take into account a constantly expanding use of diamond tools.

The volume of diamond mining should apparently be set according to the experience

of the most highly developed capitalist country - the U. S. A., which annually acquires (and, according to other sources, consumes) up to 12, 000, 000 carats of industrial diamonds. As is known, the greater part of industrial diamonds are used in working steel objects. Therefore we think it is possible in establishing the needed quantity of diamond raw material to make calculations on the basis of the production of steel, which is the basic material in machine building. If one compares the consumption of diamonds by the U. S. with the production of steel, which is 120, 000, 000 tons per year, it is possible to discover a certain principle: 1, 000, 000 carats of diamonds are necessary per 10, 000, 000 tons of steel. On the basis of this quite conditional comparison, one can set the consumption of diamonds by U. S. S. R. industry, given the 1960 production of steel as 68, - 300, 000 tons, at 6, 000, 000 carats. A certain correction should be made in calculating the demand for diamonds in the industries of the countries of the socialist camp. It is obvious that in the near future our demand for diamonds will be reckoned at 7, 000, 000 to 9, 000, 000 carats per year. Diamond production on such a scale is quite realistic if prospected and estimated reserves are taken into account. These figures amount to about one-half the world's diamond production. The U. S. S. R. will become one of the major diamond producers.

... The construction of lapidary plants and the training of specialists in the U. S. S. R. must begin immediately, concurrently with the construction of diamond-mining enterprises.